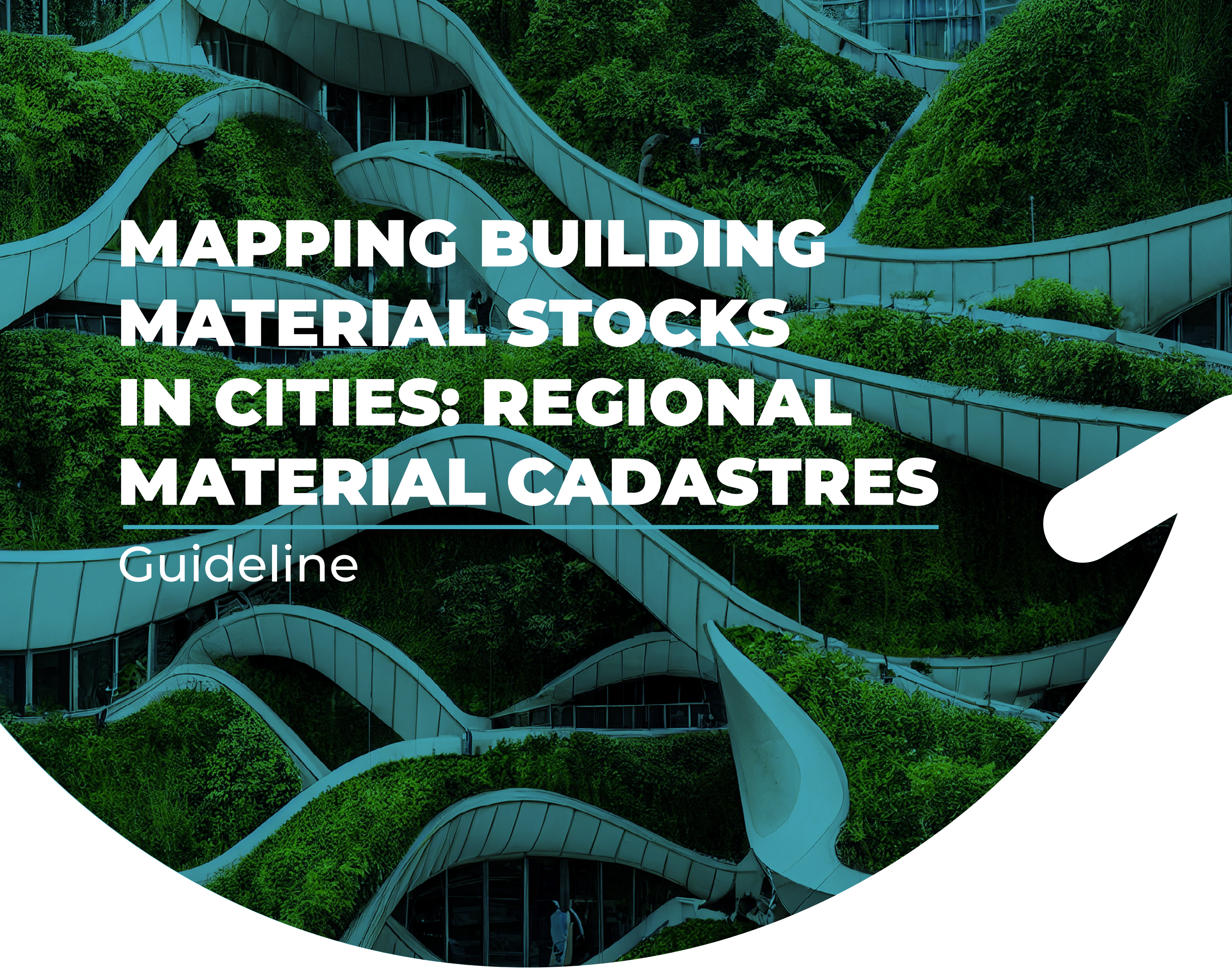

MAPPING BUILDING MATERIAL STOCKS IN CITIES: REGIONAL MATERIAL CADASTRES

Guideline

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CirCon4Climate

December 2023

CirCon4Climate

This publication has been developed as one of the activities of CirCon4Climate project.
This project is part of the European Climate Initiative (EUKI) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

Supported by:

Federal Ministry for Economic Affairs and Climate Action

European Climate Initiative EUKI

on the basis of a decision by the German Bundestag

Title:	Mapping building material stocks in cities: regional material cadastres
Subtitle:	Guideline
Version:	Final Draft
Date:	6 December 2023
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1. Introduction

This guideline introduces the topic of mapping construction material stocks in the built environment (buildings and infrastructure). Based on this, appropriate cadastre concepts can be developed in cities and regions and the necessary steps specified. This will be the subject of pilot applications in the CC4C project.

In order to live, humans have built buildings, roads and infrastructure, thus creating a built environment. This built environment is constantly maintained, renovated and further developed, leading to significant material flows. New building materials are continuously in demand, while old demolition materials must be disposed of. These processes associated with maintaining and developing the built environment account for 35-45% of global material flows and generate 30-40% of worldwide waste. This suggests that the built environment is organized in a linear way.

The built environment also represents an enormous, human-made and thus anthropogenic resource stock. The, materials embedded in buildings, roads and infrastructures can be recycled and repurposed in new construction projects. Furthermore, extending the lifespan of existing buildings through refurbishment and maintenance, along with using innovative resource efficient and climate friendly materials and changing consumer patterns (e.g. using less floor space), can significantly reduce the need for new raw materials. Such practices contribute to resource conservation, landscape preservation, and climate protection. Cities and communities that adopt these practices by:

- Recycling and reusing demolition materials ("closing"),
- Extending the use of buildings and roads ("slowing"), and
- Implementing efficient, innovative building materials ("narrowing"),

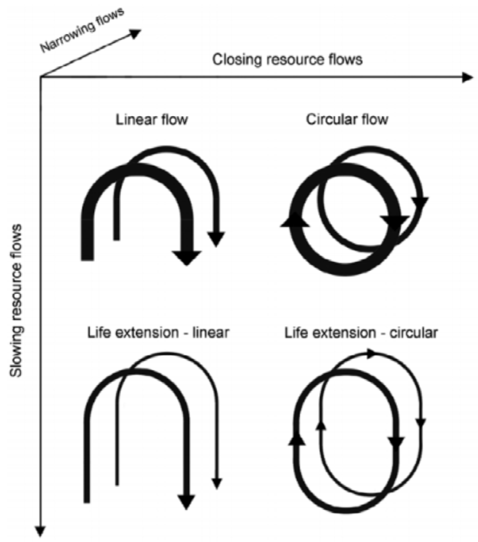
are embracing a "circular" approach.

Figure 1: Strategies of Circular Economy

Bocken et al. (2016) define three strategies for the move towards a circular economy:

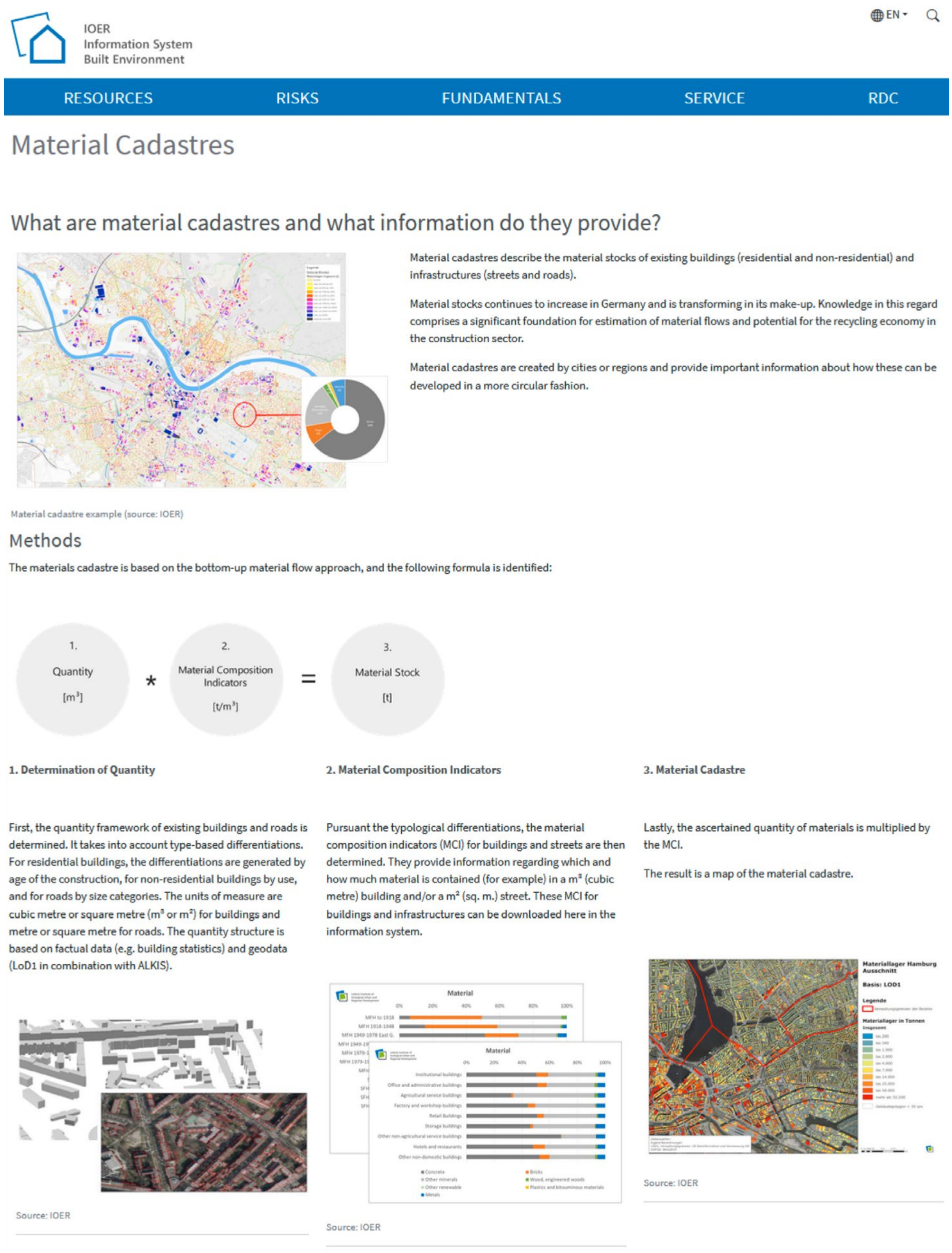
- Slowing loops (reuse),
- Cosing loops (recycling) and
- Narrowing loops (efficiency)

Bocken, N.; Miller, K.; Steve Evans, S. (2016): Assessing the environmental impact of new Circular business models. Conference "New Business Models" - Exploring a changing view on organizing value creation – Toulouse, France, 16-17 June 2016



To achieve circularity in construction, we need detailed knowledge and information about the building materials in the existing building stock and their dynamic. This is where regional material cadastres become relevant. Material cadastres use information on the materiality of buildings based on building typologies and corresponding material indicators and combine these with building volumes, e.g. by using building volumes indicated in digital GIS-based maps (Figure 2: https://ioer-isbe.de/en/resources/material-cadastres). These cadastres enable the simulation of demolition, new construction, and circular development options for cities and regions. They are particularly useful for those involved in urban and environmental planning, the construction and recycling industry and stakeholder groups beyond. The applications are diverse, ranging e.g. from construction planning (how much and where will new construction take place, can recycled materials be used?) to securing raw materials (are there sufficient raw material mining capacities available regionally?) to waste management (how much and what construction waste is generated?) to climate protection (how much gray emissions can be saved in construction through low-CO_2 construction methods?).

Figure 2: Material cadastre



source: https://ioer-isbe.de/en/resources/material-cadastres

With material cadastres, stakeholders can explore and test different development scenarios and understand the resulting environmental impacts in advance. It is crucial for cities and regions to collaboratively integrate cadastres in their planning processes in order to generate impact and make circularity happen.

2. Material Cadastres

2.1. What is a material cadastre?

A material cadastre captures and manages information about the existing materials in buildings and other structures of the built environment. It provides an overview of the type, quantity, and condition of the materials used in a specific area and serves as a foundation to map the dynamics of materials in the built environment within a city or region. This can be utilized to specify strategies for circular construction in cities and regions.

The creation of a material cadastre is done through the typological description of the existing stock of buildings and their linkage with corresponding material composition indicators (MCI).

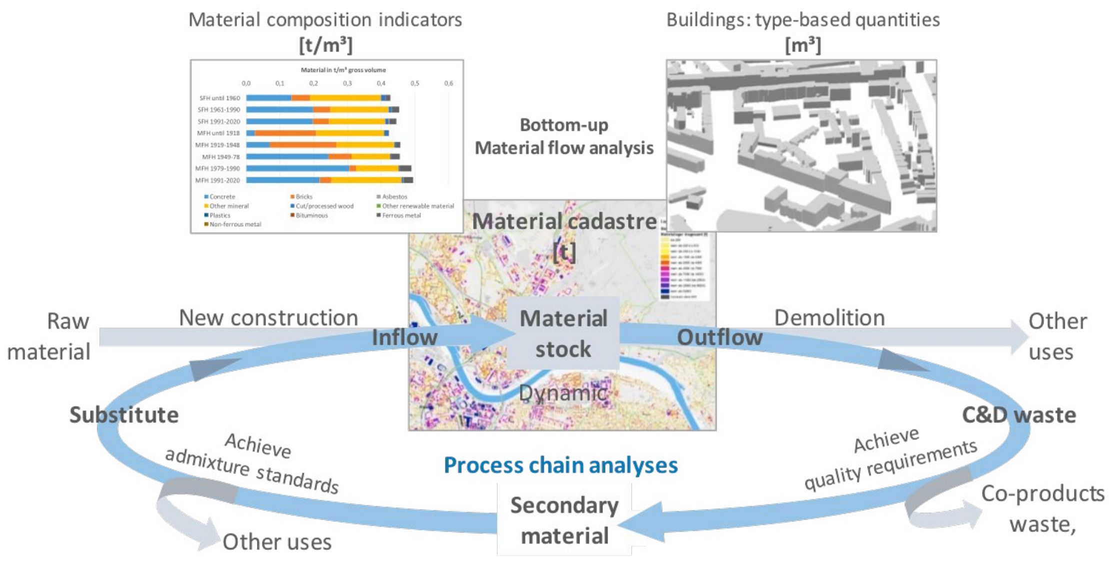
The typological description of the stock is based on a GIS analysis of building polygons and their attributes. Using geospatial data and 3D building models, information such as building function, floor area, height, and volume is defined. Additional structure type mappings and administrative boundary data allow for further differentiation.

The raw data are collected and spatially and content-wise cleaned and processed with the help of suitable geoinformation software. Spatial queries with the administrative boundary data enable the assignment of attributes to the building polygon datasets and the linkage with MCI.

Building-specific MCI describe their specific material contents in relation to the floor area or volume of the buildings. Detailed analyses of representative buildings that demonstrate typology based characteristics in terms of usage and construction methods provide the basis for this.

A material cadastre provides spatial information about the material stocks in tons for each building. By combining building material information and spatial data, the material cadastre enables efficient management and utilization of building materials. It integrates simulations of stock dynamics considering social and technical parameters. Analyses of process chains provide opportunities to quantify circularity potentials (Figure 3: MC – Methodical approach). Material cadastres contribute to resource conservation and the avoidance of grey greenhouse gas (GHG) emissions.

Figure 3: Material cadastre – methodical approach



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- Stock mapping based on digital **3-D city models**
- **Regional bottom-up MFA** based on a typology approach
- Simulation of **stock dynamics** considering social and technical parameters
- **Process chain analyses** to quantify local potential for circularity
- **LifeCycleAssessment** to calculate grey emission load

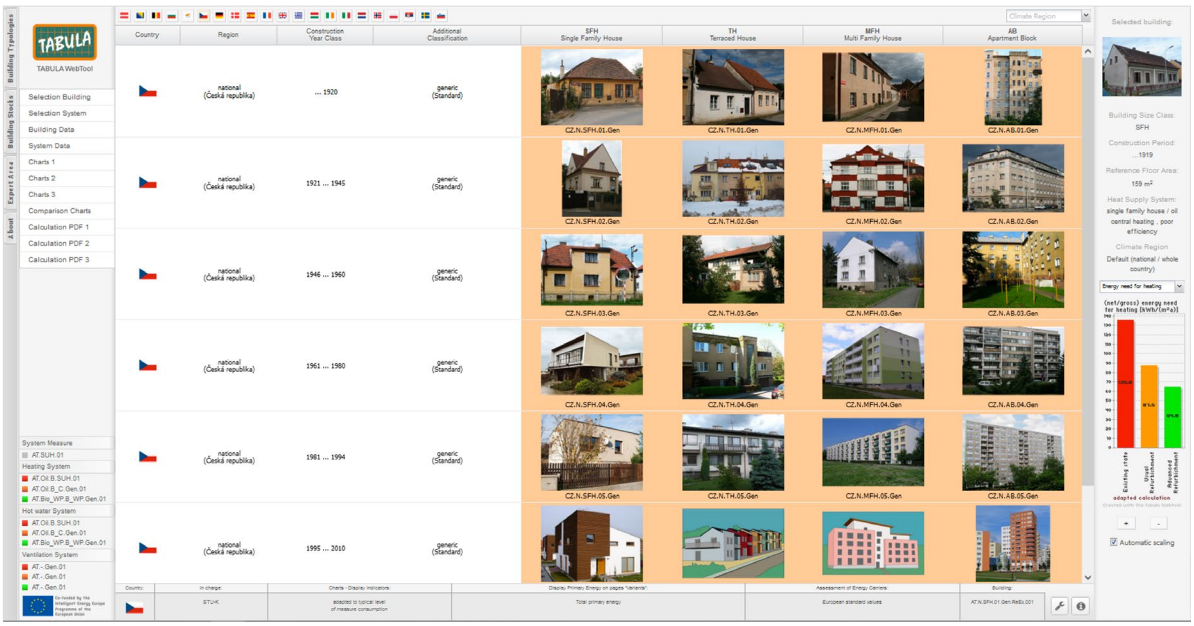
2.2. Conceptual design of a material cadaster

Material cadastre approaches offer platforms for the detection of material stocks and flows for cities and regions. These are mainly inventory approaches. Aspects of dynamisation usually focus on changes in the inventoried building stock and the inflows and outflows induced by them.

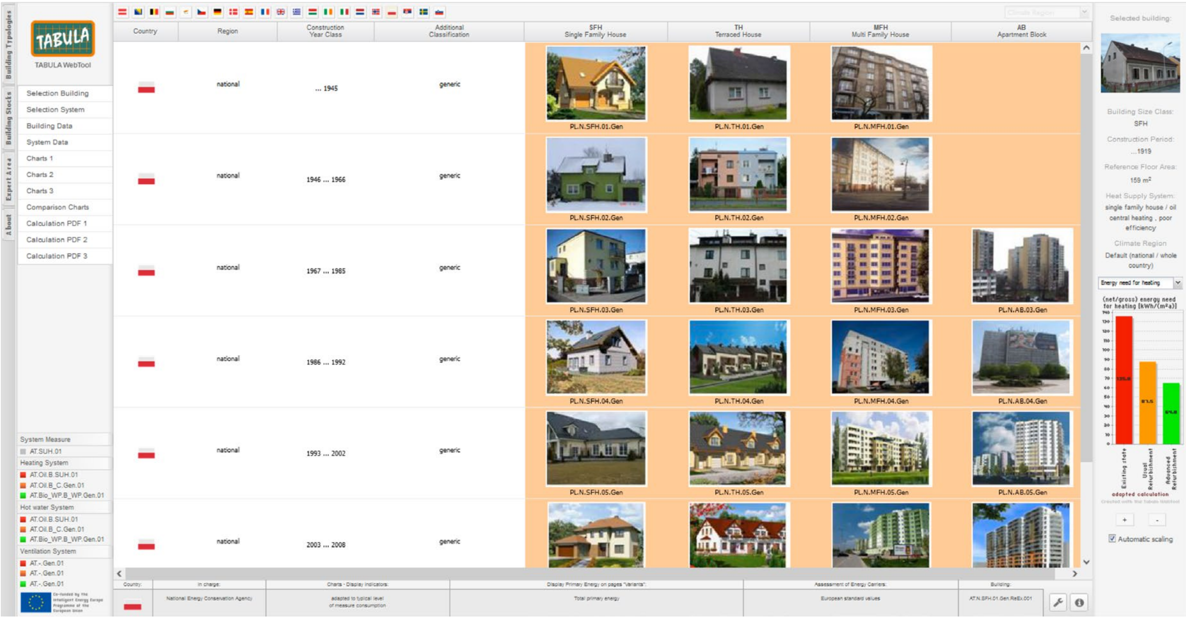
Material cadastres (MC) spatially reflect the material stock (MS) embodied in structures of a region as well as the material flows from and into the stock caused by demolition and new construction qualitatively and quantitatively. Regional MC are methodologically based on the principle of bottom-up material flow analysis (MFA) and combine it with a building type approach. The MC can be generated for buildings and roads in a region. To calculate the MS for buildings in a city or region, buildings are typed (Figure 4: TABULA-Typologies, https://webtool.building-typology.eu/#bm), quantified in m³ gross volume (gv), and multiplied by corresponding material composition indicators (MCI) in t/m³gv (formula). The result is material quantities in tons (Figure 5: Calculation for Material Cadastre). The spatialized MS of a city or region is a MC (Figure 6: Material Cadastre in tons as 3D model). Due to its life cycle orientation (MCIs are structured from raw material to building material to waste category), the MC can provide important information for municipal construction planning.

Figure 4: TABULA-Typologies

Czech Republic



Poland



Slovenia

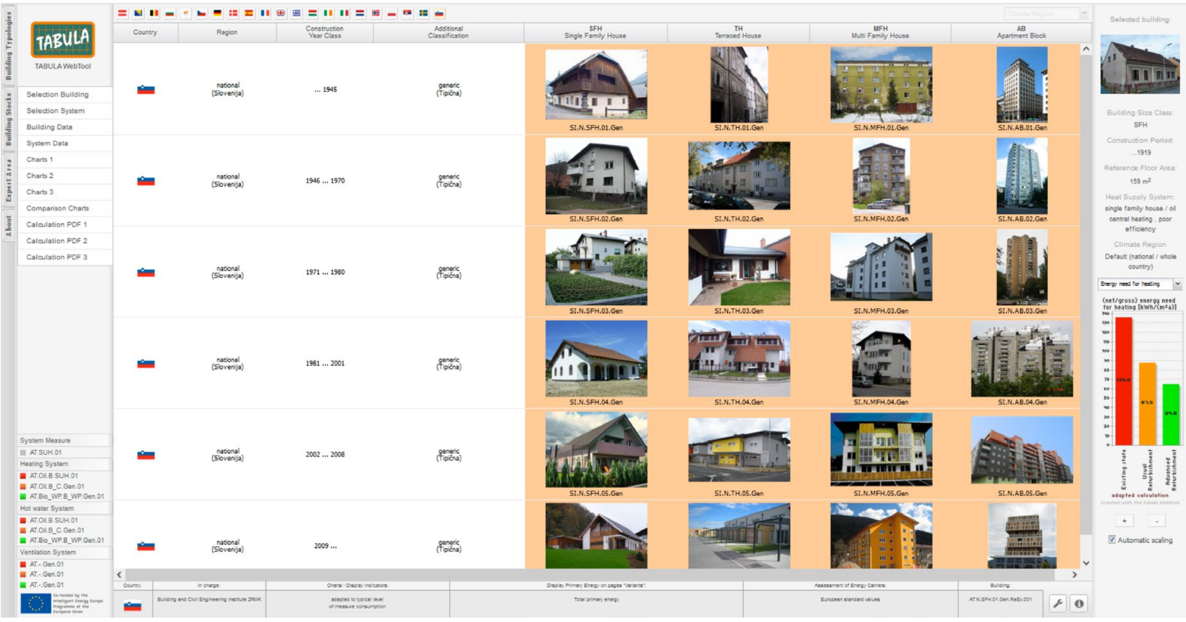


Figure 5: Calculation of material cadastre (MC)

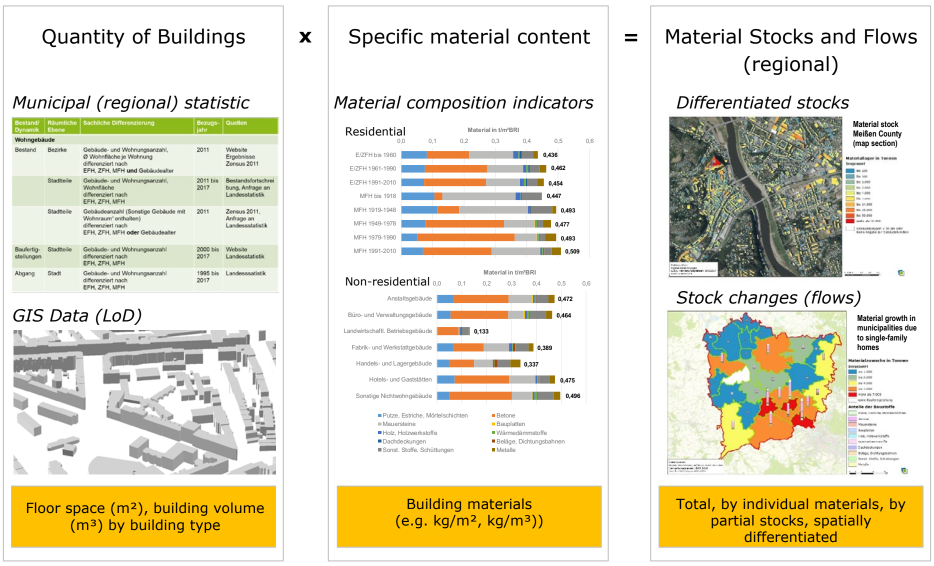


Figure 6: MC in tons

3D model of the material cadastre in tons – section of the map

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3. Scope of application of the building material cadastre

3.1. Sustainability and resource management

Resource consumption in the construction sector accounts for a large share of global material flows; 35-45% results from the provision of building materials. Savings must be made here. The material stock of the building stock must be understood as an anthropogenic resource, the use of which can contribute to saving natural resources through urban mining and recycling. To this end, it is important to know the building material stock and its dynamics, what quantities of material are contained in the buildings, what quantities of demolition are released through demolition and what quantities of building material are needed for new construction. Material cadastres (MC) help to provide corresponding knowledge and to model possible developments of cities and regions.

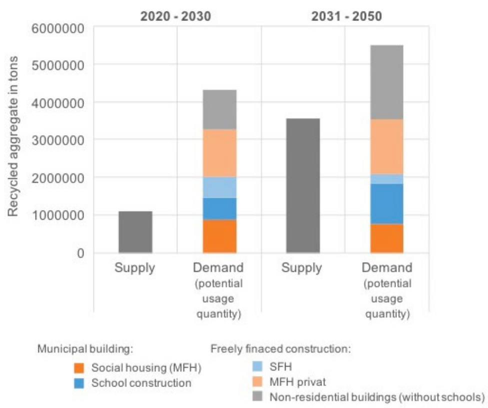
Cities, as one of the main players in the building sector, are increasingly looking for ways to influence grey energy and anchor it in local climate protection programs. So far, there is a lack of guidance knowledge and benchmarks. Material cadastres can help support this need for information and contribute to environmentally sustainable practices in multiple ways. Material cadastres can play a pivotal role in achieving sustainability goals by closing material loops through the efficient use of waste materials as secondary resources and promoting the extended use of buildings, which not only conserves resources but also reduces the overall environmental footprint. By embracing these principles and utilizing material cadastres, cities can make informed decisions, reduce their ecological impact, and actively contribute to a more sustainable and resilient future.

3.2. Possible applications and opportunities

With information from the MC and information about future potential developments, applications of the MC can be explored. For this purpose, active communication with those stakeholders who intend to use the MC is crucial in order to capture the desires and application interests of the stakeholders.

Utilizing Material Cadastres (MCs), cities can calculate the local 'supply' of high-quality secondary materials derived from the available construction and demolition (C&D) waste within the city. Simultaneously, they can determine the 'demand' for these materials driven by new construction activities (Figure 7: Example: supply and demand of recycled aggregate). This assessment allows cities to explore opportunities for conserving primary resources and promoting closed-loop systems within their regions, all while considering the various steps in material processing and adhering to local standards.

Figure 7: Supply and demand of recycled aggregate



- Using demolished concrete for recycled aggregate in concrete for new construction
- Regional analysis: Supply of recycled aggregate versus demand of recycled aggregate
- Differentiation into sub-stocks taking into account the scope of influence of stakeholders(in this case municipal stakeholders)
- Material cadaste information: Starting point to discuss new business models

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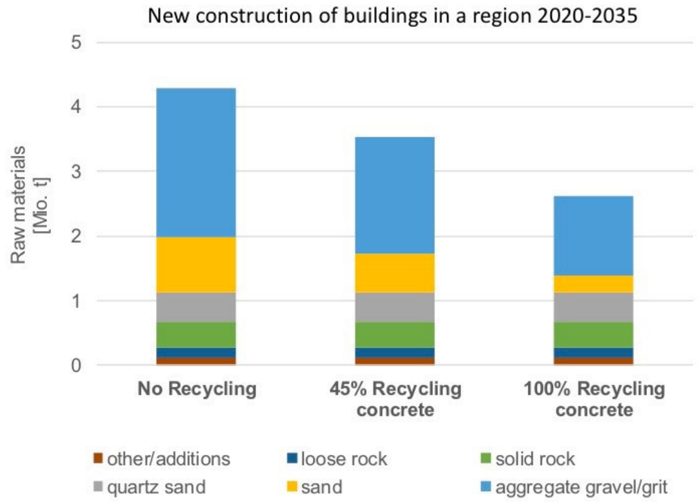
MCs play a significant role in enhancing raw material security (Figure 8: Raw material security). They categorize building materials used in new construction into distinct raw material categories, often aided by predefined recipes. These categories yield raw material quantities that can be compared against planned or approved mining volumes, providing a valuable resource planning tool.

Figure 8: Raw material security



- Regional planning:
- using recycled aggregates as a resource

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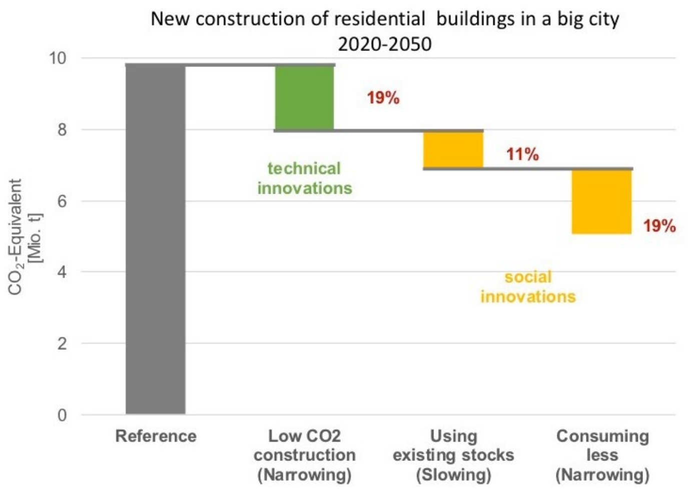
Furthermore, MCs serve as a valuable tool for assessing the environmental impact of building materials in new construction, specifically regarding grey emissions (Figure 9: Reduction of grey emissions). City planners can analyse the potential emissions savings associated with low-emission construction practices, aiding in the formulation of climate protection programs with defined target objectives.

Figure 9: Reduction of grey emissions



- Climate protection: benchmarks for grey emission reduction
- Low-carbon construction, longer use of existing buildings and living with less floor space per capita help to reduce grey emissions.

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Equipped with the material cadastre (its calculation and combination algorithms, its assumptions and specifications), and in co-process with actors who seek answers to their questions, various applications can be explored. The iterative exchange with the actors significantly influences the necessary assumptions and specifications, as well as the course of calculations and estimations.

3.3. Pre-demolition audit

In order to integrate demolition and the resulting material flows into a comprehensive urban mining concept, knowledge about the material types, quantities and their composition of a building as well as relevant knowledge about the organisation of the demolition process is needed. Material cadastres have the potential to generate this knowledge based on generic, i.e. typology-based data. This can provide benchmarks to support a demolition process that is aligned with an urban mining strategy.

4. Geodata basis and preparation of the material cadastre

4.1. Data sources and data collection

Fundamentally, the required data should encompass details about the building's area, height, volume, and its intended use. This should not involve new geodata collection, but rather utilize secondary data sources, such as local or central cadastral offices or open data platforms. It's important to consider the quality of both official and publicly available data, ensuring it's as recent as possible. Basically, 3D building models or building footprints are suitable to cover this information. If building use information is available in list form with spatial reference, this information shall be referenced to the geometry data. Additional sources like real estate cadastres or digital topographic maps, as well as block maps, may be required to fill gaps in building usage data. The data should be available in a format that is as standardised as possible for seamless processing. In relation to the 3D building models, the CityGMl format should be mentioned and reference made to the European INSPIRE data directive. Data on the building construction age and construction type with spatial reference are also required. This can be in polygon, point, or list formats with geo-coordinates or addresses. Lastly, data regarding administrative territorial boundaries is essential.

4.2. Geoinformation systems (GIS) for data preparation

A tool is needed to combine and process both spatial data and semantic information. In terms of data formats and types, the predominant geometry-related data formats will primarily include CityGML, ESRI Feature Class, ESRI Multipatch, or ESRI Shapefile data. To conduct spatial data analysis and subsequently visualize the results, a Geographic Information System (GIS) is required. Such a system allows for the integration of additional data and information, such as semantic data, which may be presented in list form but also have a spatial reference. It is crucial in any case that a linkage between the data can be established through a spatial reference such as geo-coordinates, overlay, address, or linking ID. Equally important is such a tool for data preparation, including the removal of unnecessary small structures or data conversions. There is a variety of GIS systems available, both paid and free (https://gisgeography.com/best-gis-software/). ESRI's GIS systems, such as ARC Map Pro, are widely used but require a paid license. Examples of free GIS systems include QGIS, GRASS GIS, or SAGA GIS. The choice of the best system and its availability depend on the specific requirements of the user and should be evaluated on a case-by-case basis. Interfaces for PostgreSQL databases may also be necessary. Additionally, other software solutions may be required or beneficial, such as software like FME (Safe Software) for converting CityGML data into ESRI Feature Class data. Furthermore, spreadsheet programs or statistical data processing software like "R" (e.g., R-Studio) may be necessary. The mentioned software solutions should be seen as suggestions, and their selection should always align with the available data and resources.

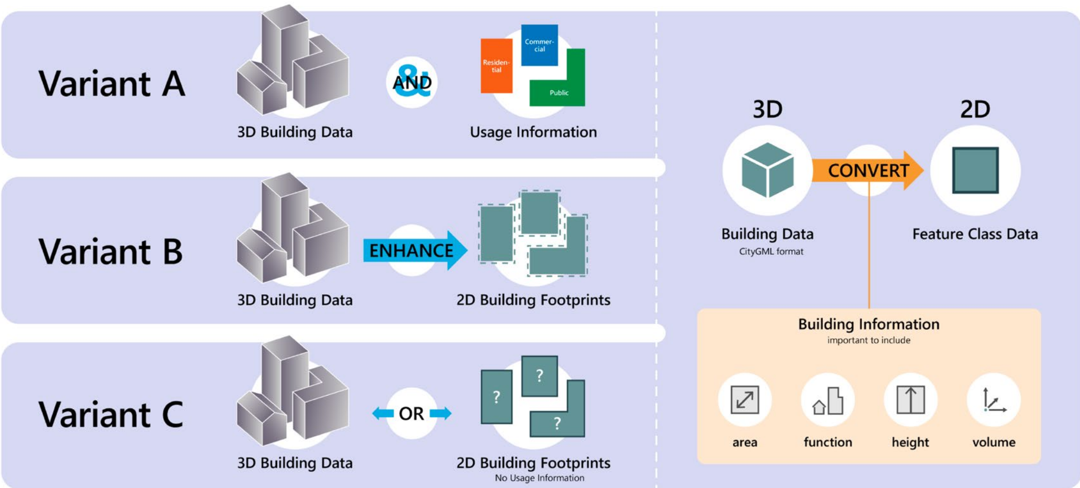
4.3. Creation of the digital city model - data preparation and integration of building information using a specific example

The goal is to obtain building polygons with building volumes and well-differentiated building functions or uses for connecting to existing material cadastres from the "Built Environment" information system (IOER) and thus determining the material stock in tons (inventory). The basis for this approach should be generally available and accessible geospatial data (see data sources and collection). The optimal data foundation is a 3D building model at Level-of-Detail 1 or 2 (LOD1 or LOD2, block model). From these models, specialized software will extract the 2D building footprint, incorporating attributes such as building function, footprint, height, and volume. These attributes are vital for subsequent GIS system calculations. In this specific case, the 3D building models provide essential information about building usage. It may occur that building functions in the dataset are insufficiently specified (e.g., regional peculiarities, data gaps). If so, there is an urgent need to enhance the LOD dataset with respect to building function. Suitable datasets that can provide sufficient information about building usage should be considered as alternatives. To further differentiate building polygons, especially residential buildings, very detailed structure type mappings can be used, such as an Extended Block Map. Additionally, geometry data is needed for delineation and final evaluation.

In this guideline, we assume the use of "ArcGIS Desktop" software. During data preparation, it is crucial to determine which information is obtained from which datasets.

In Variant A, we have 3D building models with usage information available. In Variant B, we also have 3D building models, but their purpose is to enhance the 2D building footprints. In this case, 2D footprints are preferred due to their concurrent output timeframe with the 3D models. In Variant C, we have either 3D building models or 2D footprints, but they lack usage information (Figure 10: Creation of a digital city model - data preparation and integration of building information to create a regional material cadastre). In Variants A, B, and potentially C, the 3D building data, if not already available, need to be converted from the CityGML format into 2D feature class data, for example, using FME. It is important to include information such as building area, building height, building volume, and, if applicable, building function during this process. Subsequently, in the target data, which refers to the final information carriers, small and fragmented polygons need to be removed as they can otherwise distort the results. Specific thresholds for these polygons need to be chosen based on country and dataset specifics. An example of the latter is the elimination of roofing structures that do not represent buildings in the context of the study. At this stage, blanket statements about threshold values for these polygons are not feasible.

Figure 10: Creation of a digital city model - data preparation and integration of building information to create a regional material cadastre



IOER 2023, Creation of a digital city model - data preparation and integration of building information to create a regional material cadastre

In Variant A, the majority of pre-processing is thus completed. In Variant B, information from the 3D building models needs to be spatially intersected with the 2D footprints, possibly through the creation of point features and the use of the centroid function. If a relationship exists between the datasets, like a shared ID, this can be leveraged. In Variant C, establishing a link via an ID, geo-coordinate, or unique address is necessary for information transfer. In this case, information is transferred using this method.

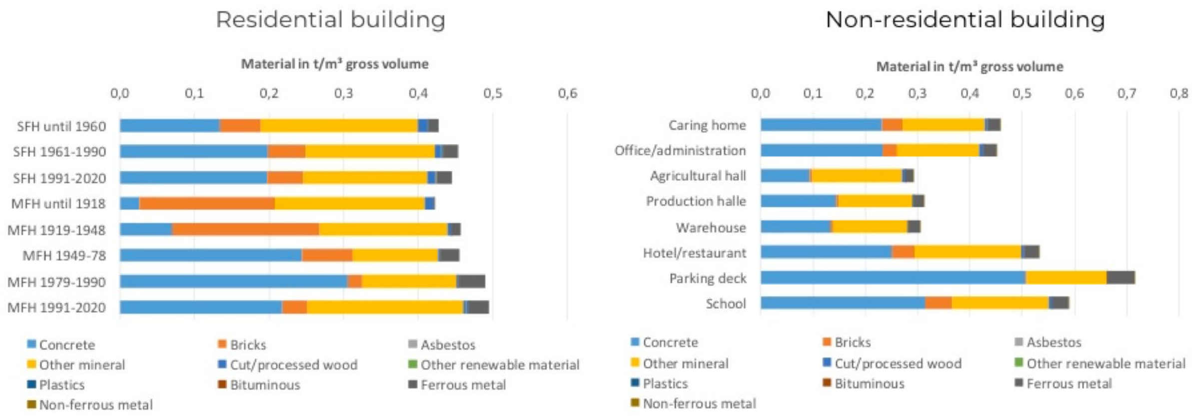
If information such as building usage is incomplete, it can now be supplemented with additional optional information (see data sources). The result is a digital city model (target dataset) that has been enriched with the necessary information. Finally, this dataset is spatially clipped according to the administrative boundaries of the study area.

5. Material composition indicators for buildings

5.1. Material composition indicators and building types

Material composition indicators (MCI) describe how many and which materials are used in buildings. MCIs exist for different building types. They are formed with the help of building representatives. The representatives reflect the characteristic features of a type (construction method, age of building, building use etc.) and are included in the type formation. Residential building types are predominantly classified based on their construction age, while non-residential structures are primarily categorized by their intended usage. Depending on the data available, approximately six to eight representatives form a type. The “Information System Built Environment” (ISBE: https://ioer-isbe.de/en/) provides information/figures for age-related residential building types as well as use-related non-residential building types (Figure 11: Typology based MCI).

Figure 11: Typology based material composition indicators (MCI)



https://ioer-isbe.de/en/resources/material-cadastres

The MCIs offer data on the overall material composition of buildings and can also break down this information into 46 distinct building material categories and five building components (foundation, exterior wall, interior wall, ceiling, roof), depending on the specific information needed (Figure 12: Structure of MCI). The 46 building material groups of the MCIs are based on the “continuity” principle (Figure 14: MCI principle of “continuity”). This means that the designated building material groups can be linked to necessary raw materials on the input side and to waste categories on the output side. The derivation of material-indexed emissions is also possible. This makes it possible to address issues of securing raw materials, waste management and recycling, and climate protection.

Figure 12: Structur of MCI

Building type: **Office and administrative buildings**

5 building elements

11/2022

46 building material groups

ID	Building material group	Building material Total (t)	Foundation (t)	Exterior walls (t)	Interior walls (t)	Ceilings (t)	Roof (t)	Building material (main group)
1	Concrete	**2986.6**	706,7	413,8	90,0	1303,9	472,2	1 Concrete
2	Lightweight concrete	**7.3**	0,0	7,3	0,0	0,0	0,0	1 Concrete
3	Bricks	**385.0**	1,1	228,8	152,8	2,3	0,0	2 Bricks
4	Bricks with insulation	**0.0**	0,0	0,0	0,0	0,0	0,0	2 Bricks
5	Brick cover/roof tiles	**13.3**	0,0	0,0	0,0	0,0	13,3	2 Bricks
6	Asbestos cement panels	**0.0**	0,0	0,0	0,0	0,0	0,0	3 Asbestos
7	Asbestos roofing	**0.0**	0,0	0,0	0,0	0,0	0,0	3 Asbestos
8	Calcareous plaster mortar	**193.9**	0,7	73,7	119,3	0,1	0,0	4 Other minerals
9	Plaster and mortar containing gypsum and anhydr	**6.9**	0,0	2,1	3,5	1,3	0,0	4 Other minerals
10	Clay and loamy plaster and mortar	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
11	Plasters with synthetic components	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
12	Calcareous screeds	**407.2**	129,7	0,2	0,0	169,4	107,9	4 Other minerals
13	Screeds containing gypsum and anhydrite	**63.6**	0,0	0,1	0,0	63,5	0,0	4 Other minerals
14	Dry screed containing gypsum and anhydrite	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
15	Screeds with synthetic components	**97.3**	0,0	0,0	0,0	97,3	0,0	4 Other minerals
16	Sand-lime bricks	**441.2**	0,0	243,4	197,9	0,0	0,0	4 Other minerals
17	Aerated concrete blocks	**46.9**	0,0	6,7	40,2	0,0	0,0	4 Other minerals
18	Concrete blocks	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
19	Mud bricks	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
20	(Gypsum) plasterboards	**35.4**	0,0	0,0	20,6	14,6	0,2	4 Other minerals
21	Mineral building boards	**3.9**	0,0	3,7	0,0	0,0	0,2	4 Other minerals
22	Mineral thermal insulation materials	**36.1**	0,0	12,7	5,5	4,9	13,0	4 Other minerals
23	Concrete roof tile covering	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
24	Fiber cement roofing	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
25	Slate cover	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
26	Substrate layer (green roof)	**0.0**	0,0	0,0	0,0	0,0	0,0	4 Other minerals
27	Mineral fillings	**659.5**	631,8	0,3	0,0	4,6	22,7	4 Other minerals
28	Glass	**13.1**	0,0	13,1	0,0	0,0	0,0	4 Other minerals
29	Natural bricks	**10.8**	1,2	8,9	0,2	0,4	0,0	4 Other minerals
30	Other mineral building materials	**0.1**	0,0	0,1	0,0	0,0	0,0	4 Other minerals
31	Timber/Lumber	**82.7**	0,0	12,6	2,1	42,5	25,5	5 Wood, engineered woods
32	Processed wood	**18.1**	0,0	11,0	7,0	0,0	0,0	5 Wood, engineered woods
33	Renewable thermal insulation materials	**0.0**	0,0	0,0	0,0	0,0	0,0	6 Other renewable
34	Straw/Reed cover	**0.0**	0,0	0,0	0,0	0,0	0,0	6 Other renewable
35	Other materials non-mineral	**0.0**	0,0	0,0	0,0	0,0	0,0	6 Other renewable
36	Petroleum-based thermal insulation materials	**8.3**	1,0	1,7	0,0	3,0	2,6	7 Plastics
37	Plastic roofing	**0.0**	0,0	0,0	0,0	0,0	0,0	7 Plastics
38	Petroleum-based coverings, geomembranes	**1.4**	0,2	0,4	0,0	0,6	0,2	7 Plastics
39	Bitumen roofing	**2.5**	0,0	0,0	0,0	0,1	2,4	8 Bitouminous minerals
40	Bituminous coverings, waterproofing membranes	**0.0**	0,0	0,0	0,0	0,0	0,0	8 Bitouminous minerals
41	Metal roofing	**0.0**	0,0	0,0	0,0	0,0	0,0	9 Ferrous metals
42	Ferrous metals	**319.2**	60,8	35,5	8,3	167,9	46,7	9 Ferrous metals
43	Coverings containing aluminum, sealing membranc	**0.0**	0,0	0,0	0,0	0,0	0,0	10 Non-ferrous metals
44	Aluminum	**13.7**	0,0	3,3	0,3	10,1	0,0	10 Non-ferrous metals
45	Copper	**0.6**	0,0	0,2	0,0	0,0	0,5	10 Non-ferrous metals
46	Other non-ferrous metals	**2.4**	0,0	0,7	0,0	0,0	1,7	10 Non-ferrous metals
	Total	**5857,2**	**1533,2**	**1080,3**	**647,9**	**1886,6**	**709,2**	
	Areas and volumes							
	Areas of building components (m²)		1011	2295	2880	2666	1174	
	Areas and volumes according to DIN 277							
	Main usable area (m²)							
	Residual usable area (m²)							
	Usable area (m²)	2.387						
	Service area (m²)	161						
	Circulation area (m²)	14						
	Net floor area (m²)	3.215						
	Construction area (m²)	419						
	Gross floor area (m²)	3.634						
	Gross volume (m³)	12.931						

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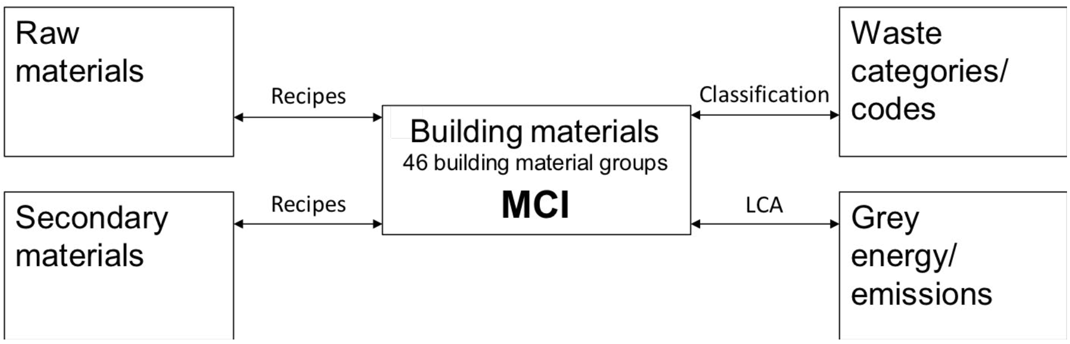
Example:
- Office and administrative building

Differentiations:
- 46 building material groups and
- 5 building elements
- 46 building material groups can be aggregated into upper groups:
- 1-concrete, 2-bricks, 3-asbestos,
- 4-other minerals, 5-wood/engineered woods, 6-other renewable, 7-plastics,
- 8-bitouminous minerals, 9-ferrous metals, 10-non-ferrous metals

https://ioer-isbe.de/en/resources/construction-data/non-residential-buildings/office-and-administrative-buildings-1

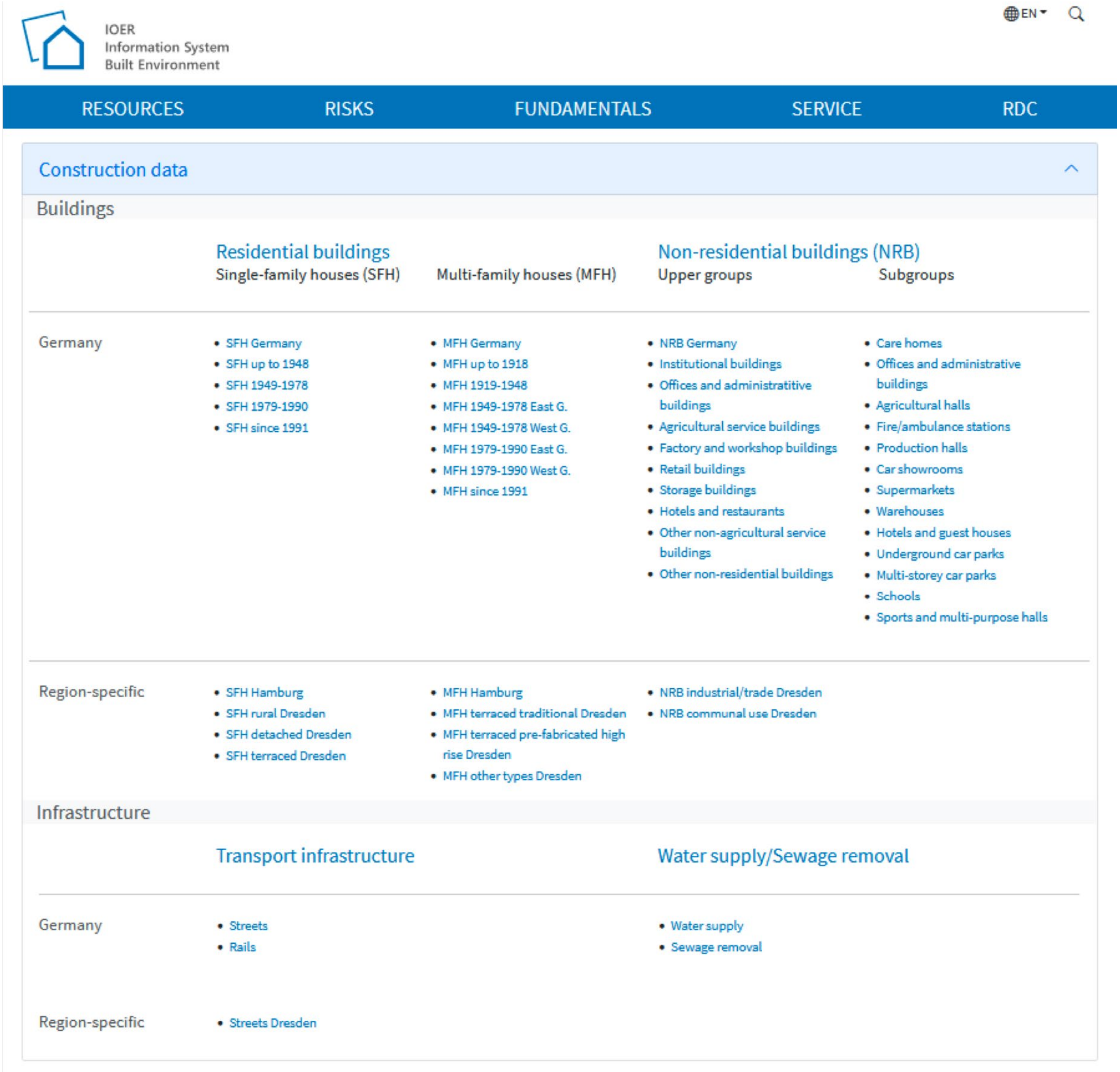
Figure 13: MCI systematics based on principle of "continuity"



5.2. Databases for material composition indicators using the example of ISBE

The “Information System Built Environment” of the IOER provides material cadastre data for various building and infrastructure types (Figure 14: Overview construction data, https://ioer-isbe.de/en/resources/construction-data/construction-data-menu). Residential buildings are categorized based on their construction age, with four age groups specified for single-family houses and five for multi-family houses. Non-residential buildings, on the other hand, are classified according to their intended use, comprising nine major categories and 13 subcategories. Depending on your needs, you can select a building type and view its corresponding building profile. This profile contains all the essential information and data regarding areas, volumes, building materials, raw materials, waste categories, grey emissions, as well as various material cadastre values (e.g., t/m² GFA, t/m² usable area, etc.), and it can be freely downloaded as an Excel spreadsheet (Figure 15: Example schools). It’s important to note that regional specifics should be considered when interpreting the material cadastre values and adapting them to local construction characteristics, such as building methods.

Figure 14: Overview construction data



https://ioer-isbe.de/en/resources/material-cadastres

Figure 15: Data Set

IOER
Information System
Built Environment

EN

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Description

Schools

Schools

… are buildings that are fitted with standard classrooms as well as rooms for technical instruction (e.g. physics/chemistry labs). In addition, such buildings contain staff rooms, conference rooms and preparation rooms. Other required facilities are sanitary rooms, as well as space for technical fittings and caretaker services. Usually schools also possess an assembly hall or similar large space for gatherings and performances. The entrance area of schools is often large and well furnished.

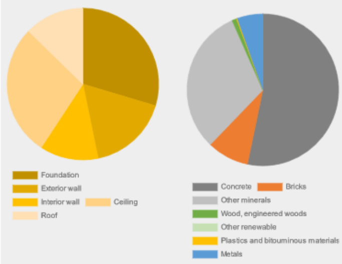
Schools are generally multi-storey in design, constructed as reinforced-concrete load-bearing frames with masonry walls. Hence, the primary building materials are reinforced concrete and brick (Gruhler, Deilmann 2015).

Floor areas

[m²]

Building material

9,085 t (0.589 t/m³ GV)



Photos: J. Krauß/IOER-Media

Materiality

Schools

Material composition indicators (t)

The detailed data on material contents and building characteristics are presented here in Excel format. The building material allocations can be taken from the building material classification.

Download (.xls)

ID	Building material group	Total	Foundation	Exterior wall	Interior wall	Ceiling	Roof
1	Concrete	4,840.14	1,652.68	381.73	170.10	1,846.65	788.98
3	Bricks	749.63	-	432.31	317.32	-	-
5	Brick cover/roof tiles	61.45	-	-	-	-	61.45
8	Calcareous plaster mortar	276.88	-	117.41	159.47	-	-
12	Calcareous screeds	807.85	272.90	-	-	440.82	94.13
16	Sand-lime bricks	1,008.15	-	554.84	453.31	-	-
20	(Gypsum) plasterboards	29.53	-	-	29.53	-	-
21	Mineral building boards	5.15	-	5.15	-	-	-
22	Mineral thermal insulation materials	60.27	-	7.61	4.25	-	48.41
27	Mineral fillings	631.08	631.08	-	-	-	-
28	Glass	13.21	-	13.21	-	-	-
31	Timber/Lumber	88.52	-	6.21	-	-	82.31
36	Petroleum-based thermal insulation materials	15.93	4.42	4.98	-	6.49	0.04
38	Petroleum-based coverings, geomembranes	2.07	0.45	0.39	-	0.67	0.56
42	Ferrous metals	485.21	128.54	31.11	-	251.67	73.89
44	Aluminum	2.20	-	1.70	0.49	-	-
46	Other non-ferrous metals	7.55	-	1.90	-	-	5.65

Main group	Differentiated raw material categories	
Mineral (stones, soils)	Gravel/Grit	Aggregate (gravel, grit)
	Sand	Sand
	Industrial minerals	Quartz sand
	Loose rock	Clay/loam
		Kaolin/feldspar (silicate minerals)
	Solid rock	Limestone/ hydrated lime/ quicklime
		Gypsum/anhydrite
		Natural stones (diabase, basalt, dolomite)
	Other/additives	Additives

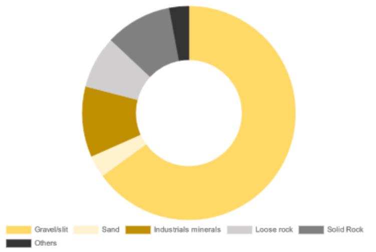
Ingredients and raw materials are determined with the help of recipes.

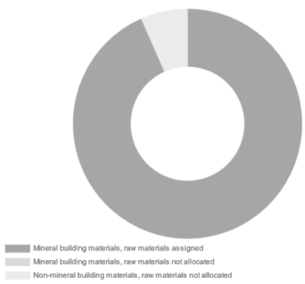
Raw material

Schools

Raw material categories (t)

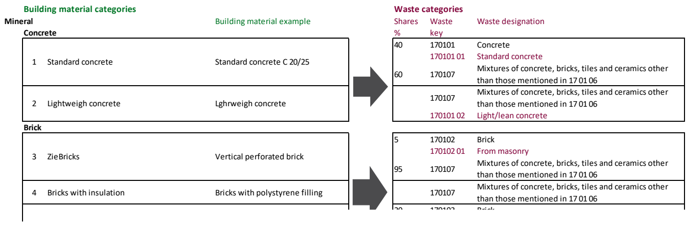
Mineral raw material categories





The allocation of mineral building materials to raw material categories is based on formulas. These specify the type and quantity of raw materials required for the production of the mineral building materials. The differentiation according to raw material categories forms the basis for the estimation of raw material requirements as a contribution to the resource conservation discussion.

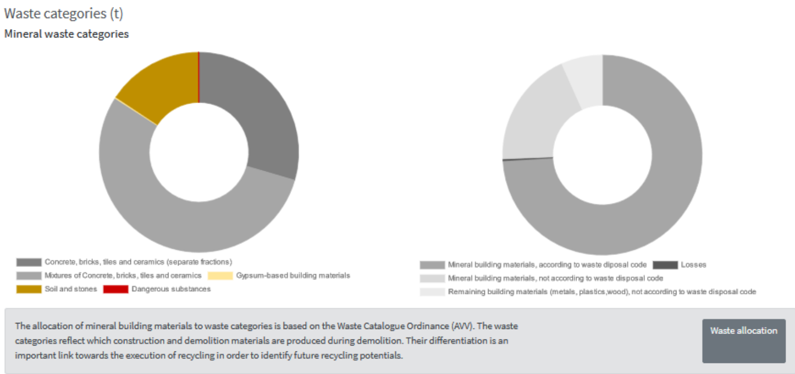
Raw material classification



Waste

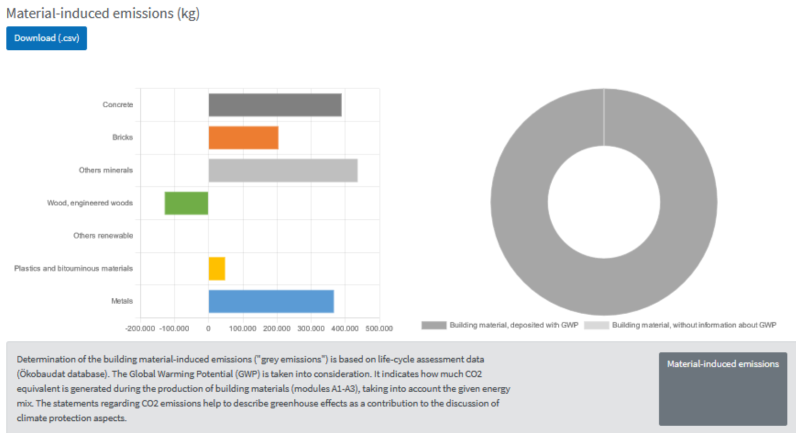
Waste categories are determined with the help of the waste classification rules

[Schools]



CO_2 - emissions

[Schools]



https://ioer-isbe.de/en/resources/construction-data/non-residential-buildings/schools

5.3. Example of building databases in European countries

The IOER ISBE building database for material composition indicators (https://ioer-isbe.de/en/), which is used as an example in this guideline, is one way of obtaining the relevant information. In the Czech Republic and Germany, the building structure types are quite similar, so the values can be used here with slight modifications. In other European countries the adaptability has to be checked. Other possible sources for deriving material composition information are data libraries and platforms such as Ecoinvent (https://ecoinvent.org/the-ecoinvent-database/), Ökobaudat https://www.oekobaudat.de/no_cache/en/database/search.html), GaBi (https://sphera.com/life-cycle-assessment-lca-database/) or Environmental Product Declarations (https://ibu-epd.com/en/epd-programme/). Another possible source of information can be the EU project TABULA, which is more focused on energy aspects (https://www.iwu.de/1/research/gebaeudebestand/tabula-en/).

6. Creation of a material cadastre for buildings

6.1. Creation of the material cadastre - material stock

The digital city model (target dataset) generated as described in ***Chapter 3.3*** must be supplemented with material composition indicators (MCI) to create the material cadastre (MC) (Figure 3: MC: methodical approach).

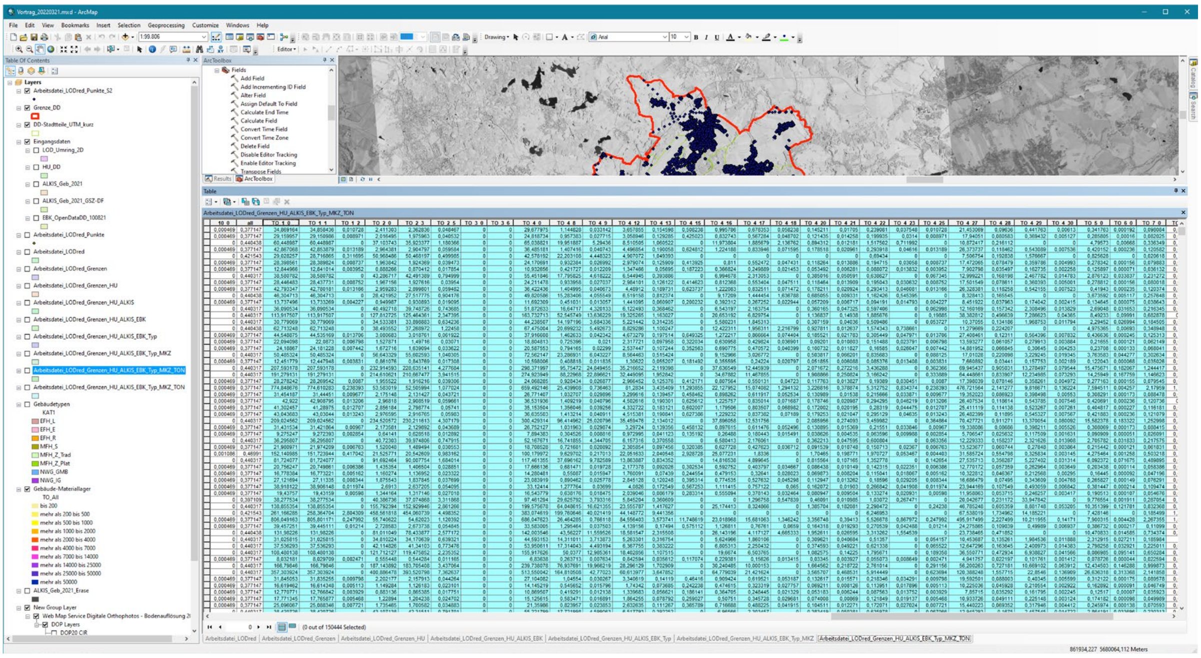
The central point for creating a MC is now the assignment of individual target dataset building polygons to categories for which MCIs in t/m³ are available in the "Information System Built Environment" (https://ioer-isbe.de/en/resources/construction-data/construction-data-menu) (mentioned here as a specific example). This is done iteratively in constant coordination with the MCI handler, taking into consideration the following questions: What types of buildings can be distinguished using the available GIS datasets, and what level of detail do the MCIs provide for this purpose? Concerning non-residential buildings, for example, the building records in Germany are relatively detailed, but MCIs are not available in the same level of detail. For residential buildings, there are very detailed MCIs. However, whether a distinction of residential buildings in the GIS is feasible with the building records must be examined on a case-by-case basis.

To determine the building usage or type for each polygon in the target building dataset, it is now necessary to assess information from various data sources related to function or use and record it in an attribute column along with the building category. This attribute column serves as the connection point for the MCIs. For residential buildings, four single-family house types and five multi-family houses types are distinguished. The MCIs are provided for all these types in the "Information System Built Environment" (https://ioer-isbe.de/en/resources/construction-data/construction-data-menu) (used here as an example). The MCIs are split into 46 building material groups. Aggregations in upper groups and total are possible. Upper groups can be for example: (1) concrete, (2) bricks, (3) asbestos, (4) other minerals, (5) wood/engineered woods, (6) other renewable, (7) plastics, (8) bitouminous minerals, (9) ferrous metals, (10) non-ferrous metals (Figure 12: Structure of MCI).

This table needs to be prepared in a spreadsheet program so that it can be linked to the attribute table of the target dataset in the GIS. This notably involves transposing the table so that the building categories become row headers and simplifying the material designations significantly. The table must also be free of special formatting (Figure 16: Example data set table in GIS). The building category as a row header serves as the key field for table linkage and must be written exactly as the entries in the building category attribute column in the target dataset. The table is then linked to the target dataset in the GIS system. It's important to integrate the data firmly and not just create a data linkage, as this can lead to performance issues in subsequent calculations. As mentioned earlier, MCIs are provided in t/m³. To calculate the material stock, it is necessary to multiply these MCIs by the building volume (Figure 5: Calculation of material cadastre).

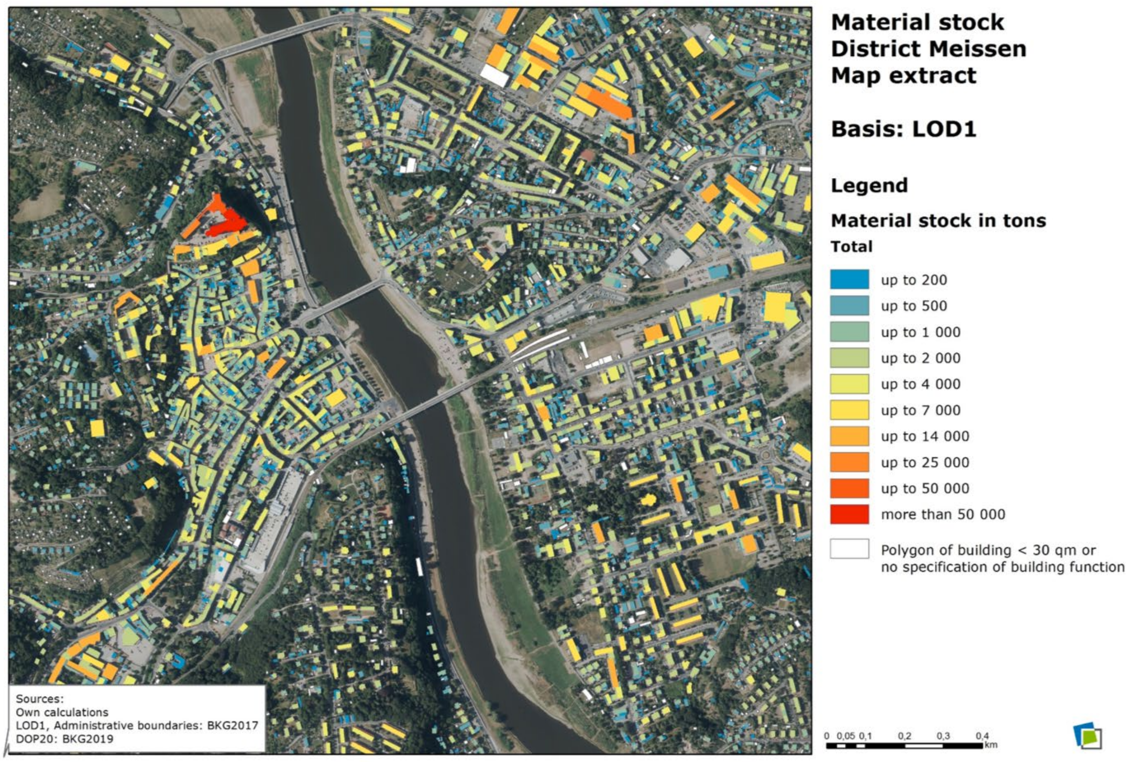
To write the result into the table, a new attribute column needs to be created. This must be done for all material groups. As a result, the material stock in tons (t) will be specified for each building polygon (Figure 17: MS in tons for each polygon). This marks the fundamental completion of the technical creation of the material cadastre. For improved readability of the attribute table, alias names can also be assigned to the column headers.

Figure 16: Data set table in GIS



IOER 2023, Example data set table in GIS

Figure 17: Material stock in tons for each building polygon

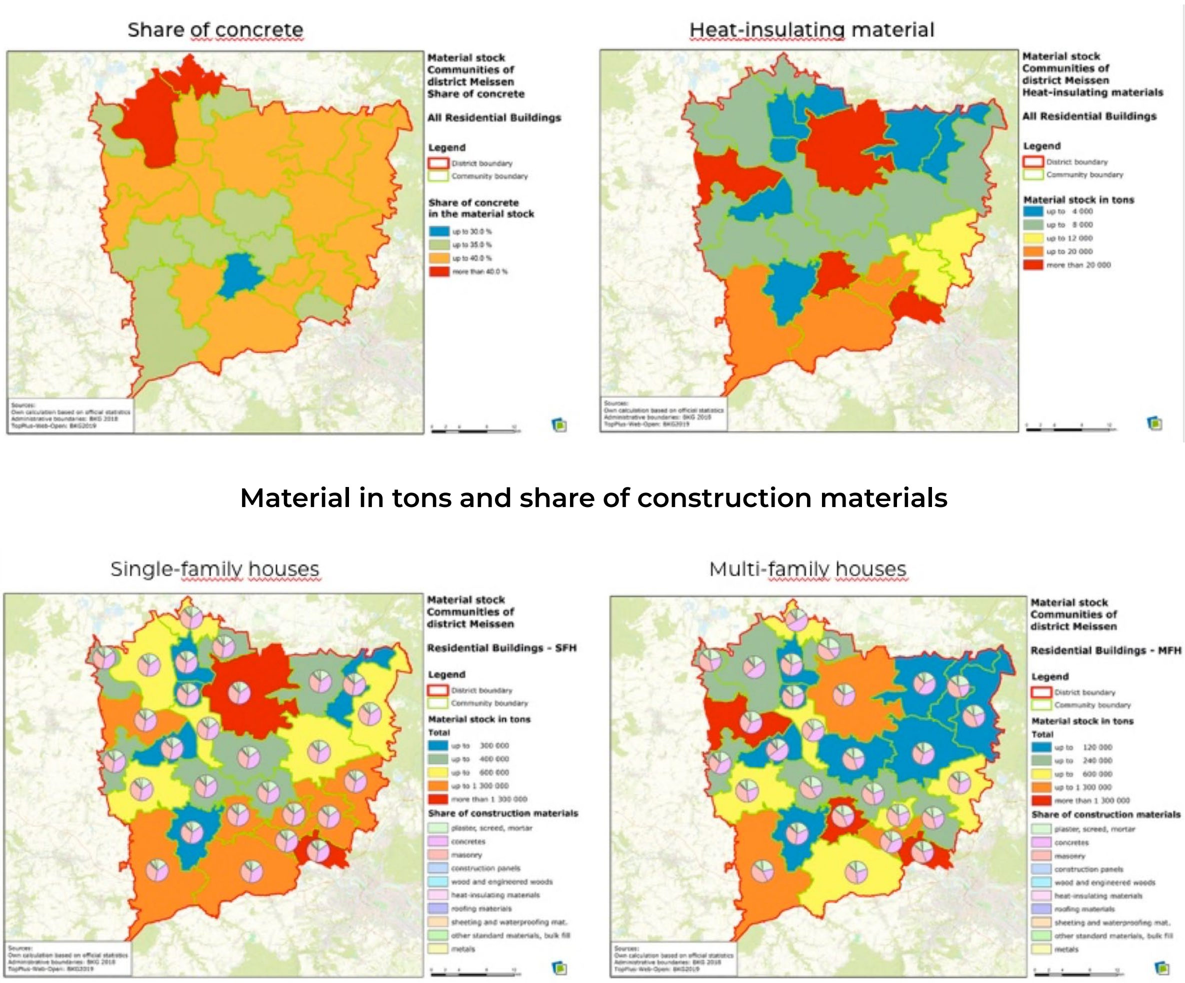


Example: District Meissen

IOER 2021, KartAL IV

When formatted in a layout, the material stock for various material groups within the study area can be displayed on maps. Additionally, statistical analyses can be performed using table functionalities (Figure 18: Examples for analyses).

Figure 18: Different possible analyses



Example: District Meissen

IOER 2021, KartAL IV

6.2. Matching with contextual real data - flow

Flows represent inflows and outflows into and out of the material stock. Inflows correspond to the construction of new buildings (new construction), while outflows signify the demolition of entire buildings (demolition). The stock changes as a result of both new construction and demolition. The starting point (Status Quo), which can be approached through two methods: (A) Ex-post analysis, often relying on statistics (specific data from construction activity statistics, demolitions, and new constructions), and (B) Ex-ante analysis, which involves dynamic assumptions-based estimates. Dynamics are assessed through the utilization of: Population-based new construction/demolition ratios (m² per capita), inventory-based rates (Percentage of the inventory), and approaches based on building lifespan (e.g., 80 years for residential, 40 years for non-residential). Specific examples are determined based on the context and requirements.

Example Dresden (Germany):

To calculate the dynamics of material inflow and outflow into the anthropogenic storage of the city, a simplified categorisation of building types into residential buildings, industrial and commercial buildings, and public buildings for non-residential structures is employed. For residential buildings, an analysis of vacancy activation and renovation is excluded because the developed MCIs do not provide information on the materiality of these activities. Quantitative estimation of residential construction requires referencing relevant reports, such as those on population and household projections for the study area, which address both the qualitative and quantitative demand for housing.

To calculate the material flow for **"Residential Buildings"**, the average dwelling size in the study area is used. An example of an average dwelling size is 70.0 square meters. When creating the material cadastre independently, it is advisable to always use the most up-to-date available value for this purpose. The conversion of living area [m²] into Gross Building Volume (GBV) [m³] is done using a conversion factor, which can be obtained from appropriate statistical sources. An example of the average value of this factor is 4.0 m³ GBV/m² living area. For calculations, this value should always be updated with the latest available data. Since this calculation does not differentiate between residential building types, it is necessary to create an average residential building type. This is done by averaging the materials used in residential building types.

Now, the annual material flow for residential buildings in the study area can be calculated as an illustrative example.

For this purpose, the MCI defined for the average residential building in t/m³GBV is multiplied by the corresponding quantity in m² living area/a. The quantity in m² living area/a is first converted into m³GBV/a using the conversion factor "living area to gross building volume". The calculations are made for both: Demolition (material supply) and new construction (material demand).

The calculation of the material supply follows a similar process to the calculation of material demand, wherein newly constructed or demolished housing units are incorporated into the formula. Ambiguities arise from the allocation of housing units that were demolished in non-residential buildings. Due to their small proportion relative to demolished residential building units, they have a minor impact on the result, tending to underestimate the material supply.

To estimate material demand and supply, suitable data extrapolated for the study period must be used. For calculating the material flow for **"Non-Residential Buildings"**, appropriate statistical data from the respective year must be relied upon. This data includes both construction completions and demolitions, expressed in cubic meters of Gross Building Volume (GBV). To determine the material demand, the MCI in t/m³GBV (for "industry & commercial" and for "public/common") is multiplied by the respective quantities in m³GBV/a. If only quantities in m² useable area/a are available, a conversion factor (for example 6.35 m³ GBV/m² usable area) is used, similar to the calculation for residential buildings.

6.3. Updating and maintaining the city model

The input geodata for the city model, as well as the material indices for calculating the materiality, should also be updated if there is an update or calculation of new time periods. This applies especially to the building data with the core information on building use, building height, volume and building floor area. In addition, the material composition indicators that may represent new building types must be included. Currently in Dresden (Germany) a regional material cadastre is in the development and testing phase, including its associated maintenance activities.

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