CREATE Embedding advanced urban material stock methods within governance processes to enable circular economy and cities resilience

CREATE project. Conceptual model and material composition vocabularies for the project

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Abstract	The CREATE project aims at supporting urban transformation processes towards the circular economy by making an inventory of the existing material stocks within urban construction, developing reliable scenarios for future expected material flows, and providing governance arrangements on how to approach the circular economy transition. This deliverable aims to investigate and propose a vocabulary framework for the CREATE project, to integrate material and waste description in the different case studies and living labs of the project and their respective databases. The second objective of the deliverable is to propose a conceptual framework for the CREATE project tool. A common vocabulary of material proposition is proposed.
Keywords	Common vocabulary, material classification, benchmark, circular economy

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1 INTRODUCTION

1.1 CREATE project

The CREATE project aims at supporting urban transformation processes towards the circular economy by making an inventory of the existing material stocks within urban construction, developing reliable scenarios for future expected material flows, and providing governance arrangements on how to approach the circular economy transition. The project focuses on the largest urban infrastructures and communal assets, namely buildings, municipal roads, and water- and wastewater pipes. A truly transdisciplinary consortium works with a mixed research design that integrates quantitative modelling with qualitative study and design of governance aspects.

The project will further improve already existing, validated, and applied tools and arrangements and combine them with new digitalization technologies to inform decisionmakers and enable a circular built environment. This is achieved by engaging with a wide range of stakeholders in a co-creation process with three urban living labs and six fellow cities in five countries, which will result in numerous capacity building moments throughout the entire project.

A thorough analysis of best practices of cities steering the circular economy transition together with new governance interventions will result in concrete proposals of tailored governance arrangements for the participating cities including a concrete proposal for an upscaling strategy for Europe.

The CREATE project follows a set of strategic underpinnings that connect the different work packages in three dimensions:

1. A living lab approach that is used throughout all work packages and allows for an integrated co-production of the project with stakeholders from the quadruple helix;
2. A multi-scalar capacity building approach, where the use of the living labs as the focal point of the work developed, complemented by the dissemination of knowledge to fellow cities and an outreach to urban networks in Europe, will allow for an optimized scalable process;
3. A tailored and adaptable approach that is based on the pre-existing conditions of the urban living labs and fellow cities, i.e., existing data, methods and governance procedures already being utilized by the stakeholders and providing them with new knowledge.

1.2 Deliverable purpose and objectives

This deliverable presents two main objectives:

1) To investigate and propose a vocabulary framework for the CREATE project, to integrate material and waste description in the different case studies and living labs of the project and their respective databases;
2) To propose a conceptual framework for the CREATE project tool.

MFA approaches are adapted to model material flows and estimate the mass going to different waste treatment ways. In the framework of circular economy, recycling is not the only action - other strategies such as reuse or refurbishment are even more valuable. As such, the integration of reuse-relevant information in material cadasters is necessary. Reuse requires information in terms of functionality and not only in terms of mass (number of windows or window surfaces instead of glass/aluminum mass). This deliverable is a first step to bridge both concepts.

The CREATE project targets three cities, namely Rennes (France), Gothenburg (Sweden) and Vienna (Austria) where previous work has been conducted on material stock in buildings. This deliverable investigates the following aspects for each of the three cities:

- How was building material composition described in Rennes, Gothenburg and Vienna? From this, a common vocabulary framework is proposed for CREATE;
- How can building material description be linked to reuse purposes?
- How to connect material categories/vocabulary and European waste codes?

In software development, conceptual models serve as foundational frameworks that help developers understand, design, and communicate complex systems and processes. These models abstract real-world concepts into simplified representations, facilitating the comprehension and management of intricate systems. The conceptual model of CREATE is the result of consultations with stakeholders of the living labs and it is also the outcome of an overview of several existing tools and projects.

2 MATERIAL COMPOSITION AND WASTE VOCABULARIES

2.1 Background of the study

As mentioned in the introduction, the CREATE project aims at developing a “tailored and adaptable” tool based on existing data and stakeholders’ procedures to provide a

decisionmaking support. To ensure comprehensiveness and homogeneity of living labs' tools and to facilitate the tool development, a common classification of living labs' databases is required.

The first step is to understand existing data in each living lab, which facilitates the development of a common classification. This classification should reflect the construction materials used for buildings of the living labs, and can be completed for each living lab (Gothenburg, Rennes Métropole, and Vienna) according to their needs and data availability.

2.2 Available databases

As mentioned previously, the three city-specific existing databases are the starting points of this study. To enhance this work and ensure its consistency, two additional data classifications are used. The first one is the Eurostat waste codes. Showing the correspondence with the waste categories aims at linking our work with the available national statistics about waste recovery. The second data classification is a material classification used in an article written by researchers of the French scientific center for building - CSTB (Tirado et al., 2021). This comparison ensures that the data used within CREATE is adapted to other similar previous scientific works. All data classifications are presented below.

2.2.1 Gothenburg

Data about Gothenburg comes from the MIC (Material Intensity Coefficients) database created by Chalmers (Gontia et al., 2019, 2018) (see D2.1 for details). Gothenburg uses a system of flexible classification, with MICs easily re-worked into any required material classification. As such, the data remained at the element/product level (e.g. roof panel, porous fiberboard…) rather than precise material categories until a CREATE classification would be reached. Nevertheless, an understanding of the content of the data was required to inform such CREATE classification, and a first conversion (e.g., roof panel is made of wood) was performed to better understand the materials under consideration in Gothenburg data. All connections are available in the attached Table 12. Please note that connections induce bias since we do not consider composite materials. Still, the exercise was successful in giving a good overview of the materials in Gothenburg data. The classification is presented in Table
1.

Table 1 : Material categories for Gothenburg by Chalmers

Gothenburg
Concrete
Stone
Brick
Gypsum
Glass
Clay
Mineral wool
Foam insulation
Bitumen
Sand (aggregates)
Iron/Steel
Copper/other
Wood solid
Wood products
Polymer

2.2.2 Rennes Métropole

Data about stocks and flows of construction materials was produced during a previous work by CitéSource for Rennes Métropole (see D2.1 for details). The work uses a two-tier classification. The classification is presented in Table 2.

Table 2 : Material categories for Rennes Métropole by CitéSource

Database materials-group names	***Database material names***
Concrete	Concrete
	Concrete block
	Concrete pavement
Stone	Stone (surface)
	Cobblestone
Brick	Solid clay brick
	Hollow clay brick
Gypsum	Plaster
Glass	Glass
Other mineral non metallic	Slate
	Earth masonry
	Tiling and roof tiles
	Mortar
	Asbestos cement
	Mineral wool

Table

Asphalt concrete	Aggregates for asphalt concrete
	Bitumen
Aggregates for road, ballast and paving	

Excavated materials	
Metals	Steel
	Cast iron
	Aluminum
	Zinc
Wood	Wood
	Chipboard
Plastic	Polyvinyl chloride (PVC)
	Polystyrene
	Polyurethane
	High density polyethylene (HDPE)

2.2.3 Vienna

Data about Vienna was retrieved from Lederer et al. (2021), who focused on the main materials of a building. Consequently, some materials are not accounted for. The classification is presented in Table 3.

Table 3 : Material categories for Vienna by Lederer and al. (2021)

Database material names
Concrete
Brickwork
Mortar/Plaster
Gravel and sand
Mineral wools
Polystyrene
Iron/steel
Glass
Wood

2.2.4 Additional examples of databases

2.2.4.1 Eurostat waste code

Eurostat (2010) developed a classification to facilitate the production of "comparable and reliable data on waste generation and treatment clear definitions and a common

understanding of waste classification". This classification, whose focus is on waste streams, is presented in Table 4.

*4 : Eurostat waste codes for the building sector (*hazardous waste) (Eurostat, 2010)*

EU Waste code	***Description***
17 01 01	concrete
17 01 02	bricks
17 01 03	tiles and ceramics
*17 01 06**	mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing hazardous substances
17 01 07	mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06
17 02 01	wood
17 02 02	glass
17 02 03	plastic
*17 02 04**	glass, plastic and wood containing or contaminated with hazardous substances
*17 03 01**	bituminous mixtures containing coal tar
17 03 02	bituminous mixtures other than those mentioned in 17 03 01
*17 03 03**	coal tar and tarred products
17 04 01	copper, bronze, brass
17 04 02	aluminum
17 04 03	lead
17 04 04	zinc
17 04 05	iron and steel
17 04 06	tin
17 04 07	mixed metals
*17 04 09**	metal waste contaminated with hazardous substances
*17 04 10**	cables containing oil, coal tar and other hazardous substances
	cables other than those mentioned in 17 04 10
17 04 11	soil and stones containing hazardous substances
*17 05 03**	soil and stones other than those mentioned in 17 05 03
17 05 04	dredging spoil containing hazardous substances
*17 05 05**	dredging spoil other than those mentioned in 17 05 05
17 05 06	track ballast containing hazardous substances
*17 05 07**	track ballast other than those mentioned in 17 05 07
17 05 08	insulation materials containing asbestos
*17 06 01**	other insulation materials consisting of or containing hazardous substances
*17 06 03**	insulation materials other than those mentioned in 17 06 01 and 17 06 03
17 06 04	construction materials containing asbestos
*17 06 05**	gypsum-based construction materials contaminated with hazardous substances
*17 08 01**	

Table

17 08 02	gypsum-based construction materials other than those mentioned in 17 08 01
*17 09 01**	construction and demolition wastes containing mercury
*17 09 02**	construction and demolition wastes containing PCB (for example PCB-containing sealants, PCB-containing resin-based floorings, PCB-containing sealed glazing units, PCB-containing capacitors)
*17 09 03**	other construction and demolition wastes (including mixed wastes) containing hazardous substances
17 09 04	mixed construction and demolition waste other than those mentioned in 17 09 01, 17 09 02 and 17 09 03

2.2.4.2 Other works

Many other scientific publications propose material intensity data for different countries, regions or cities. These include, for example, a global database compiling MIs existing in the literature (Heeren and Fishman, 2019). This open MI database is being used in the European project FutuRaM.[1] In their work, the authors identify three main categories of materials: biobased, metals and minerals.

Figure 1: Material categories in Heren and Fishman (2019)

Category/Aggregation				Material	No. of data points
Total	Total w/o other materials	Bio-based		Wood	278
				Paper/Cardboard	5
				Straw	0
		Metals		Steel	228
				Copper	72
				Aluminum	105
				Other/unspecified metal	95
		Construction mineral	Concrete, cement & aggregate	Concrete	257
				Cement	65
				Aggregate (gravel, sand, slag)	135
			Other construction material	Brick	184
				Mortar/Plaster	146
				Mineral fill	90
				Plaster boards/gypsum	101
				Adobe	1
				Asphalt	21
				Bitumen	73
				Natural Stone	46
				Cement asbestos sheet	32
				Clay	8
				Siding (unspecified material)	3
	Other materials			Ceramics	103
				Glass	207
				Plastics	72
				Polystyrene	30
				PVC	20
				Lineoleum	43
				Carpet	3
				Heraklith	21
				Mineral Wool	110
				Insulation (unspecified material)	29
				Other (unspecified material)	81

Another example of a material classification is that of Tirado et al. (2021), their work aims at applied an automatized a multiscale characterization of construction materials based on geographic information system on the French region of Paris. The classification is presented in Table 5.

[1] www.futuram.eu

Table

5 : Material categories in Tirado et al. (2021)

Concrete and stone
Bricks
Roof tiles
Ceramics
Gypsum (plasterboards and planks)
Insulation (mineral wools)
Insulation (other)
Metals ferrous
Metals non-ferrous
Windows
Wood (low adjuvanted)
Other NHW

3 RESULTS

All classifications can be compared in Table 6. A striking result is the differences across classifications, including in terms of scope (i.e., materials included) and terminology. For example, Rennes Métropole includes aluminum, while the Gothenburg classification mentions only copper for non-ferrous metals. Furthermore, classifications do not have the same level of precision for materials e.g. Rennes Métropole classification distinguishes several forms of concrete while Vienna classification does not. It is important to note that due to the various construction of the databases, an absolute correspondence is not ensured. For example, in some cities aggregated groups such as “non-ferrous metals” are used whereas other cities distinguish copper individually and European Waste Codes makes a clear distinction between main base metals scrap: steel, aluminum and copper.

7 : Table of comparison of all classifications.

Suggested material categories for CREATE	Rennes Métropole	Eurostat waste code	Tirado et al. (2021)	Vienna	Gothenburg (see appendix)
Concrete	Concrete	17 01 01	concrete and stone	Concrete	Concrete
	Concrete block	17 01 01			
	Concrete pavement	17 01 01			
Stone	Stone (surface)	17 01 07 [2]			Stone
	Cobblestone	17 01 07 [2]			
Brick	Solid clay brick	17 01 02	bricks	Brickwork	Brick
	Hollow clay brick	17 01 02			
Plaster (gypsum)	Plaster	17 08 02	gypsum (plasterboards and planks)	Mortar and plaster	Gypsum
Glass	Glass	17 02 02		Glass	Glass
/		No clear correspondence	windows		

Table

Tiling and roof tiles	Slate	17 01 03[2]			

Earth Masonry	Earth masonry	17 05 04			
Tiling and roof tiles	Tiling and roof tiles	17 01 03	ceramic and roof tile	Brickwork	Clay
Mortar	Mortar	17 01 01[3]		Mortar and plaster	
Asbestos cement	Asbestos cement	17 06 01 (insulation) 17 06 05 (construction materials)			
Insulation (all types)	Mineral wool	17 06 04	insulation (mineral wools)	Mineral wool	Mineral wool
		17 06 04	insulation (other)		Foam insulation

[2] In a mix of inert waste

Table

Sand and Aggregates	Aggregates for asphalt concrete	17 05 04[3]		Gravel and Sand	

Bitumen	Bitumen	17 03 02			Bitumen
Sand and Aggregates	Aggregates for road, ballast and paving	17 05 04 17 05 08		Gravel and Sand	Sand (aggregates)
Excavated materials	Excavated materials	17 05 04			
Steel and cast iron	Steel	17 04 05	metals ferrous	Iron/Steel	Iron/Steel
	Cast iron	17 04 05			
Aluminum	Aluminum	17 04 02	metals non-ferrous		
Zinc	Zinc	17 04 04			
Copper		17 04 01			Copper/other
/		17 04 07			
Wood	Wood	17 02 01	wood (low adjuvanted)	Wood	Wood solid
Panels and chipboard	Chipboard	17 02 01			Wood products
Polyvinyl Chloride (PVC)	Polyvinyl chloride (PVC)	17 02 03			
Insulation (all types)	Polystyrene	17 02 03		Polystyrene	
	Polyurethane	17 02 03			Polymer
High density polyethylene (HDPE)	High density polyethylene (HDPE)	17 02 03			
/		?	other NHW		

Although these limits are observed, a common classification is proposed (Table 8) in order to display the same material categories without having to compute or measure new data. Some complementary sub categories of materials are presented at the left (first column) in order to not lose accuracy.

Table 8 : Final proposition for the common classification

	Concrete
	Stone
	Brick
Plaster (gypsum) ***Mortar***	**Mortar and Plaster**
	Glass
	Tiling and roof tiles
	Earth Masonry
	Asbestos cement
	Insulation (all types)
	Bitumen
	Sand and Aggregates
	Excavated materials
	Steel and cast iron
	Aluminum
Wood ***Panels and chipboard***	**Zinc**
	Copper
	Wood
Polyvinyl Chloride (PVC) ***High density polyethylene (HDPE)***	**Polymer (except insulation)**

4 DISCUSSION, MATERIALS FOR REUSE

We tried to find the most appropriate material classification to assess recycling potential (waste flows, material characteristics). However, the extent to which this classification can be applied for reuse purposes remains unclear.

To answer this question, based on the buildings categories from the French regulation on building waste (PEMD)(CSTB and French Republic, 2023), we crossed material categories where some cases of reuse are notified in France (Table 9) with our common material

classification (previous section). The list of building categories is presented on appendices Table 13. The cross matrix is presented in Table 10.

This work shows that the link between building materials for reuse and recycling is challenging.

Composite products

Several products or building parts are composite in terms of materials. When recycling, materials are separated into waste fractions according to their material composition; for reuse, it is difficult to pinpoint reuseable elements when data is presented at the materiallevel and vice versa. To do so, some additional data sources are required which are not included in typical building material intensity databases (accurate model of component, bill of materials of component…). Similarly, it is difficult to know the share of reusable material in the total material quantity. There are mainly three specific cases where the translation between materials and components is an issue:

- Splitting material from a defined product to derive the bill of materials (BoM): for example, in Figure 2, a database is available at product level, and a technical sheet (ex: a FDES in France) is enough to translate product weight in BoM. Nevertheless, a large amount of technical sheets would be required (or at least an averaged material composition from literature), other uncertainty increases. The risk is that only several products having a public BoM in Environmental Product Passport would be used as reference value for the whole product stock.
- Inventorying materials to determine components, as depicted in Figure 3This case is challenging and raises considerable uncertainty. Indeed, if a BoM of building is available, deriving product/component quantities from it requires large amounts of generic data about buildings (ratio of a component, at regional or national scale, ratio by dwelling, by built-up area). If the same material (for ex. ceramics) is used by N components/products (WC, toilet, shower), the conversion of BoM into components requires an assessment based on an average number of WC/toilets/shower by dwelling or by surface. This risk to be not adapted to the desired precision of the study.
- Splitting aggregated product categories into material-level information, as depicted in Figure 4 The CERFA classification deals with product categories (e.g., windows), rather than product (e.g., wooden frame window, aluminium frame window, and the like) while the quantity of similar product is known (e.g., window count, or total window area), the material composition of each product inside the category is unknown. As a result, BoM cannot be derived from such data.

Reuse or repurpose

Several composite products are not directly usable for reuse. For example, a window (cat. 6.2.) is composed of a glass and a frame (PVC, wood, aluminum, aluminum/wood…). Due to its complexity, it could be mainly repurposed rather than strictly reused, as happened in the recent headquarters of the Council of the European Union (Brussels) where old window frames

were repurposed[4]. Even for products that roughly correspond to one material, extracting the reusable share of the material quantity remains challenging. For example, reusing solid bricks (Cat. 3.8.) is common in Belgium and the Netherlands in particular[5]. Conversely, the feasibility of reusing hollow bricks varies depending on the presence of mortar. But in BoMs, distinguishing between these two types of bricks (solid and hollow) is not easy.

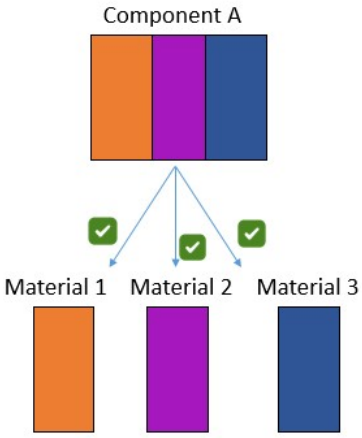
Additionally, reusability potential in general depends on many factors that cannot be evaluated solely based on a building's material composition. Other factors are critical, such as the material/component resistance, its conservation state, and more.

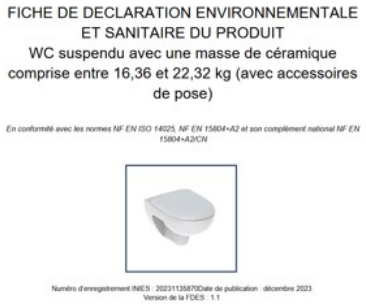
Material categorization for CREATE

To summarize, classification at the material level is adapted for recycling (like that of Rennes Métropole) approach while a product/building component classification is more suitable for reuse (like that of Gothenburg). As reuse requires many additional data (composition at product level, technical characteristics of materials, functional unit not always in mass), in the context of the CREATE project, mass-recycling oriented data is more adapted. If the project wanted to be fulfilled with a reuse approach, a second classification should be constructed, which would require extensive efforts of data collection and processing for most of the living labs.

[4] https://optigede.ademe.fr/fiche/reemploi-de-chassis-de-fenetres-pour-la-construction-du-siege-du-conseilde-l-union-europeenne , consulted in December 2023

[5] https://opalis.eu/fr/materiaux/briques , consulted in December 2023




FICHE DE DECLARATION ENVIRONNEMENTALE
ET SANITAIRE DU PRODUIT
WC suspendu avec une masse de céramique comprise entre 16,36 et 22,32 kg (avec accessoires de pose)

Example (FDES Geberit toilet bowls)	
Component A	Toilet bowl (1 unit) (mean 20,69kg)
Material 1	Ceramic (88%)
Material 2	Plastic (toilet seat cover)(10%)
Material 3	Other (2%)

Figure 2: Converting component information into a Bill of Material requires product sheets or standard product composition

Example for 10 buildings (floor surface)		
Material 1	Ceramic	Tot qty : X kg
Material 2	Plastic (toilet lid)	Tot qty : Y kg
Material 3	Other	Tot qty : Z kg

Nbr of toilet bowls Geberit (component A)? Component B (toilet bowls Grohe)?
Component C (washbasin)?

Example of data need to answer the question
- Studied scale : national, city, district
- Means value of toilet bowls in a building in function of the surface or number of rooms
- Type of toilet in function of building age and type of building
- Number of plastic for toilet compared with the amount of plastic in a building

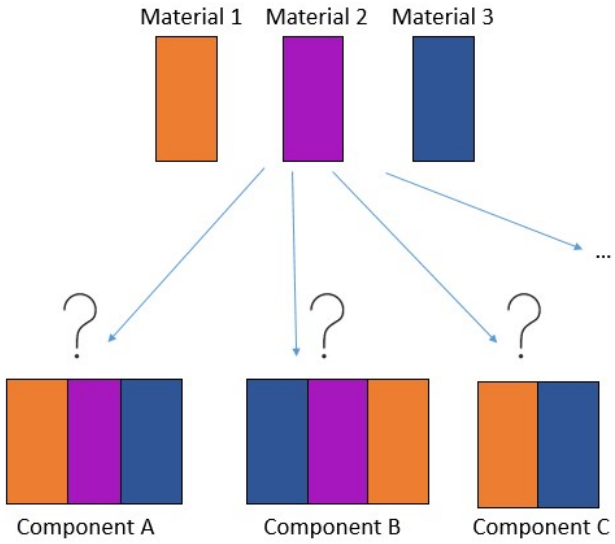
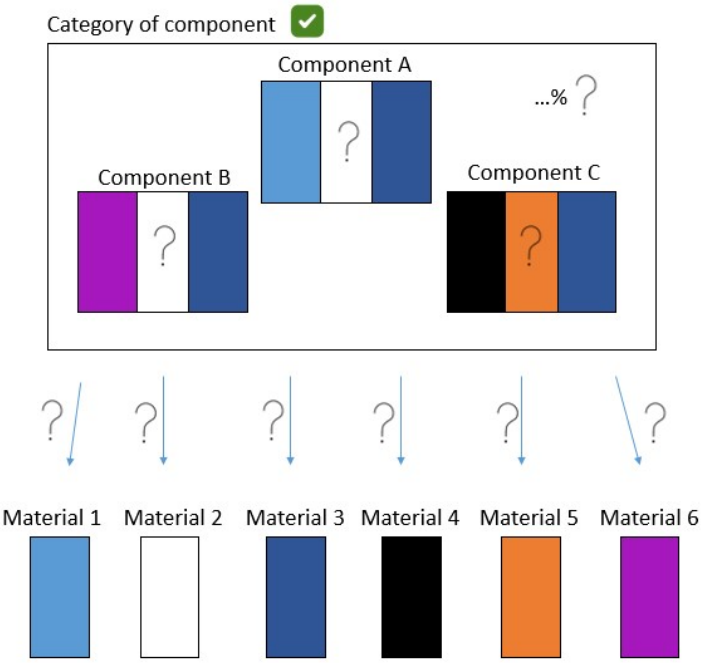


Figure 3: Converting material information into component is not possible.



Example : Windows	
Component A	Aluminium frame windows
Component B	PVC frame windows
Component C	Wood windows
Material 1	Aluminium
Material 2	Glass
...	

Which Bill of Materials ?

Example of data need to answer the question
Studied scale : national, city, district
Means value of type of windows in buildings → qty of components A?B?C?
Quantity of materials in component A?B?C?

Figure 4: Information at the level of component category (e.g., windows) is not enough to derive the component (e.g., wood frame) composition of each component (e.g., wood frame, aluminium frame). Quid of distinguishing components in a category of component

*Table 9 : Potential reusable materials, the case in France**

SUB-CATEGORY	REUSABLE MATERIALS*
1.3 Pavement	Natural stone paving stone and kerbs, raw earth paving stone
3.2 Beams	Solid wood, steel joist
3.3 Facades	Barn wood, natural slate
3.7 Insulation	Different type of insulation
3.8 Masonry	Full mud brick
4.2 Tiles	Raw clay tiles, natural slates
5.3 Ceiling	Demountable suspended ceilings
5.4 Raised floor	Demountable raised floor
5.5 Interior Joinery	Interior joinery
5.6 Metalwork	Metalwork
6.2 Windows	Windows (mainly refurbishment and repurpose)
7.1 Floor covering	Carpet tiles, solid wood parquet, terracotta tiles, cement tiles, ceramic tiles
8.1 Heating equipment	Cast iron radiators
9.3 Sanitary equipment	Toilet bowls and other ceramic equipment

*Could be re-used or refurbished; cases in France; for specific component, often with heritage value

(mainly not at industrial scale) source: optigede[5] , Democles[6], FCRBE[7] and Authors' expertise

[6] https://www.democles.org/ , consulted in March 2024

[7] https://vb.nweurope.eu/projects/project-search/fcrbe-facilitating-the-circulation-of-reclaimed-buildingelements-in-northwestern-europe/ consulted in March 2024

Table 10 : Chart crossing some reusable building components with material classification

CATEGOR Y	SUB-CATEGORY	CONCRETE	STONE	BRICK	PLASTER (GYPSUM)	GLASS	TILING AND ROOF TILES	EARTH MASONRY	MORTAR	ASBESTOS CEMENT	INSULATION (ALL TYPES)	SAND AND AGGREGATES	BITUMEN	EXCAVATED MATERIALS	STEEL AND CAST IRON	ALUMINUM	ZINC	COPPER	WOOD	PANELS AND CHIPBOARD	PVC	HDPE
1	1.3 Pavement	x	x																			
3	3.2 Beams														x				x			
	3.3 Facades						x												x			
	3.7 Insulation elements										x											
4	3.8 Various masonry			x																		
	4.2 Tiles, slates						x															
5	5.3 Suspended ceilings					x					x											x
	5.4 Raised floors																			x		
	5.5 Interior joinery																		x	x	x	
	5.6 Metalwork														x							
	6.2 Doors, windows					x										x			x		x	
7	7.1 Floor covering	x	x	x			x															x
8	8.1 Heating syst.														x							
9	9.3 Sanitary						x															

5 CREATE PROJECT CONCEPTUAL MODEL

At its core, a conceptual model is a high-level representation of the essential components, relationships, and behaviors of a system. It provides a conceptual understanding of the system's structure and functionality without delving into specific implementation details. Conceptual models abstract away complexities, enabling stakeholders to focus on fundamental concepts and their interconnections.

In the context of software development, conceptual models serve as blueprints for designing software systems. They aid in clarifying requirements, guiding architectural decisions, and facilitating communication among stakeholders with varying levels of technical expertise. By capturing the essence of a system in a concise and comprehensible manner, conceptual models lay the groundwork for successful software development endeavors.

5.1 Needs for tool development within the CREATE project

Needs related to the development of a visualization tool within the framework of the CREATE project were analyzed during WP2 (see D2.1 and D.2). The following table summarizes those needs.

Table 11 : Needs for tool development within the CREATE project

Topic	Discussion
Material stock calculation	Material cadaster is the result of a model, combining city building database with material composition information. A material cadaster (or building material stock) can be the result of a calculation made elsewhere (like in Rennes Métropole living lab), but can also be developed in an automatic way within the tool (Gothenburg).

Data visualization	The tool should allow the user: - To visualize the material cadaster and material composition of selected buildings; - To select specific buildings (e.g., a demolition project, a district).
Scenario approach	Based on the display/consultation of building information (material composition/building) the tool allows the user to select several buildings. The user can compare different circular economy strategies (% for recycling by material category, % for reuse).
LCA	It was decided to keep the degree of integration of environmental impact assessment and LCA in CREATE at a minimum. Instead, the CREATE tool allows the user to extract material/waste data, which is then used as input to the LCA model (the latter is developed as part of CREATE).

5.2 Conceptual model

Figure 5 presents the conceptual model. It contains different needs expressed by stakeholders of living labs:

- "City building database" is the reference building database for material cadaster. The maintenance and update of the database is to be performed by each city. This database can be related to national building databases as it is the case in Rennes Métropole/France.
- Material cadaster generation was considered outside the scope of the CREATE tool in the case of Rennes Métropole case study. In the case of Gothenburg, it is expected to be integrated. Presently, in the three cities of the project, the calculation of this material cadaster is the result of a manual calculation/model, but Gothenburg would be interested in an integration of such a calculation in a dynamic or automatized way. We can imagine an evolution of this work where the city building database is connected to a "material cadaster" module and calculations.
- Material cadaster is a database, with the same objects and attributes than "city building database" but with additional information. To each object where calculations were made, material cadaster associates material composition to each single object.
- Scenarios and circular economy strategies. The material cadaster of the city/district/project is used to select several buildings that would be refurbished or demolished, according to project

managers and urban planners. The amount of waste generated by these deconstruction actions can be evaluated. Circular economy strategies, the degree of reuse of materials, the repartition between landfill and recycling, can be evaluated here at a very high level. This calculation delivers a potential amount of waste and a potential amount of secondary raw materials. The consideration of real conditions and possibilities of recycling/reuse only could be assessed after diagnosis. Uncertainties are clearly disclaimed to the users.

- LCA calculations are performed outside the tool. In the previous step, different circular economy strategies applied to a project are evaluated. Each can be later evaluated by LCA impact categories (not only carbon emissions). The input information for LCA would be the different types of waste/secondary raw materials generated or avoided (more details will be available in deliverables of Work Package 5 of CREATE).

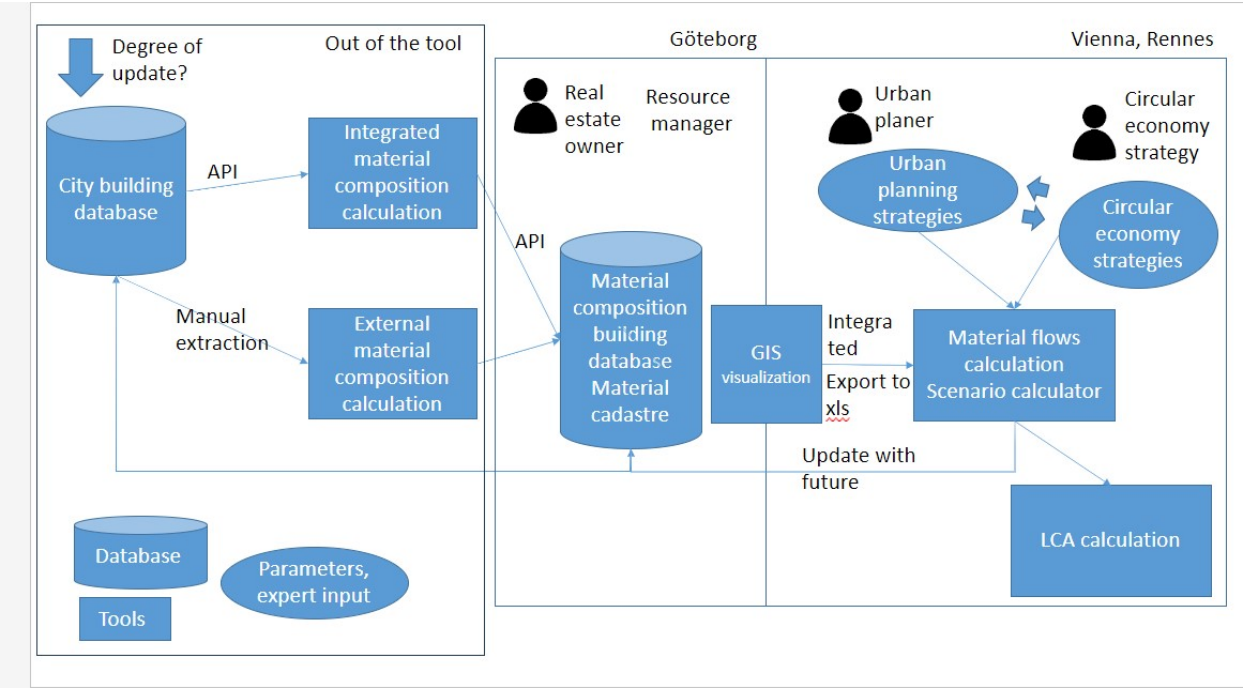


Figure 5: conceptual model of different user stories of CREATE's tool

6 CONCLUSION

Based on previous works about material stock calculations in buildings made in Gothenburg, Rennes Métropole and Vienna, a common vocabulary for the CREATE project was produced. The link with European Waste Code was also made as a way to connect to official construction and demolition waste statistics.

The possibility and challenges of integrating a cadaster of materials suitable for reuse and not only for recycling is also discussed in this deliverable. With the type of inventory of materials

per building, in mass by material, and with the diversity of construction products that can use the same material, achieving a satisfying reuse potential assessment is highly challenging. Indeed, this would require a detailed inventory of construction products, include functional units specific to each product, and a detailed description of the shares of different materials in composite products. Obtaining such data is difficult for old buildings but in the future, with the development of BIM, we can expect to obtain them.

Finally, a conceptual model for the CREATE tool is proposed. The tool allows users to access and display material cadaster information for individual buildings and download this information for further calculations such as circular economy strategies and LCA models.

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7 APPENDICES

7.1 Gothenburg material data correspondence

Table 12 : Gothenburg data classification and correspondence to a material

Element part of building	***Component names in the database***	***Suggested correspondence for the type of materials***
Roof	Truss	Wood solid
Roof	Paneling wood	Wood solid
Roof	Sheet metal	Iron/steel
Roof	Tile	Brick
Roof	Roof tile	Clay
Roof	Lath	Wood solid
Roof	Cardboard	Wood products
Roof	Tar paper 5mm	Bitumen
Roof	Syll	Wood solid
Roof	Panel	Wood solid
Roof	Roof panel	Wood solid
Roof	High board	Wood products
Roof	Concrete tiles	Concrete
Roof	Insulation	Mineral wool
Roof	Plaster board	Gypsum
Roof	Asphalt board	Wood products
Roof	Concrete	Concrete
Roof	Cork insulation	Wood products
Attic	ESP insulation	Foam insulation
Attic	Steel bar	Iron/steel
Attic	Wood beams	Wood solid
Attic	Lime mixed peat	Stone, sometimes including copper/other
Attic	Floorboards	Wood solid
Attic	Sawdust	Wood products
Attic	Syll	Wood solid
Attic	Cardboard	Wood products
Attic	Panel	Wood solid
Attic	Porous fiberboard 12mm	Wood products
Top floor	Insulation	Mineral wool
Top floor	Paper	Wood products
Top floor	Plaster board	Gypsum

Top floor	Wood beams	Wood solid
	Sawdust	Wood products
	Sawdust and Lime mixed peat	Wood products, Stone
	Floorboards	Wood solid
	Syll	Wood solid

Panel	Wood solid
Coke ash	Copper/other
Plaster	Concrete
Porous fiberboard	Wood products
Slag	Copper/other
Mineral wool	Mineral wool
RC Slab	Concrete, iron/steel
Gypsum board	Gypsum
Concrete	Concrete
Brick	Clay
Lime gravel	Stone
Steel bar	Iron/steel
Over concrete	Concrete
Reinforced concrete	Concrete, iron/steel
Slab 13	Concrete
Cardboard	Wood products
Wood shaving	Wood products
Concrete slab	Concrete
Estrich	Concrete
Crushed light concrete	Concrete
Foil	Foam insulation
Vertical planks	Wood solid
Horizontal planks	Wood solid
Sawdust	Wood products
Cardboard 5mm	Wood products
Syll	Wood solid
Porous fiberboard	Wood products
Wood beams	Wood solid
Plaster board	Gypsum
Insulation	Mineral wool
Vertical wood beams	Wood solid
Horizontal planks	Wood solid
Plank	Wood solid
Cardboard	Wood products
Plaster (clay mortar)	Clay
Plaster	Concrete
Panel	Wood solid
Porous fiberboard	Wood products
concrete	Concrete
Brick	Clay

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Brick bearing	Clay
Brick nonbearing	Clay
Concrete blocks	Concrete, iron/steel
Mineral wool (nonbearing wall)	Mineral wool

Aerated concrete (nonbearing wall)	Concrete

Plaster board (nonbearing wall)	Gypsum
Lightweight concrete (nonbearing wall)	Concrete
Wood beams	Wood solid
Sawdust	Wood products
Sawdust lime peat mixed	Wood products, Stone
Lime mixed peat	Stone, sometimes including copper/other
Floorboards	Wood solid
Syll	Wood solid
Cardboard	Wood products
Panel	Wood solid
Porous fiberboard	Wood products
Plaster board	Gypsum
Insulation	Mineral wool
Lamelparket	Wood products
Plaster	Concrete
Coke ash	Copper/other
Mineral wool	Mineral wool
concrete	concrete
Ext gypsum board	Gypsum
Lime gravel	Stone
Steel structure	Iron/steel
Steel bar	Iron/steel
Reinforced concrete slab	Concrete, iron/steel
Fiber board	Wood products
Concrete 5 cm	Concrete
Concrete 20 cm	Concrete
Sand	Stone
Estrich	Concrete
Horizontal planks	Wood solid
Vertical planks	Wood solid
Panels inside	Wood solid
Panels outside	Wood solid
Wood beams	Wood solid
Wood beams V	Wood solid
Wood beams H	Wood solid
Syll	Wood solid
Sawdust	Wood products
Cardboard	Wood products

Interior wall Interior wall	Plaster	Concrete
	Plaster (reed)	Gypsum
Interior wall	Plasterboard	Gypsum
	Plasterboard inside	Gypsum

Interior wall

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Asphalt board	Bitumen
Bricks	Brick (SF), Clay(MF)
Bricks(Stone)	Concrete
Limestone brick	Concrete
Grout	Concrete
Tar paper	Bitumen
Paper	Wood products
Porous fiberboard 12 mm	Wood products
Insulation	Mineral wool
Insulation (cell foam)	Polymer
Fiberboard 3.5mm	Wood products
Particleboard	Wood products
Foil	Polymer
Plaster ext (clay mortar)	Clay
Plaster int (clay mortar)	Clay
Plaster ext	Concrete
Plaster int	Concrete
Planks	Wood solid
Reeds	Wood solid
Porous fiberboard	Wood products
Asphalt paper	Bitumen
Plywood	Wood products
Concrete brick	Concrete
Hard mineral wool	Mineral wool
Gypsum boards	Gypsum
Brick first floor	Clay
Wood wool	Wood products
Lightweight Concrete	Concrete
Foam insulation	Foam insulation
Asbestos cement board	Concrete
Plaster terasit	Concrete
Plaster lime	Concrete
Mineral wool	Mineral wool
Ext gypsum boards	Gypsum
Plast foil	Foam insulation
EPS insulation	Foam insulation
Wood façade	Wood solid
Steel beams vertical	Iron/steel
Wood beams	Wood solid
Panel	Wood solid

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Basement ceiling
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Basement ceiling

Floorboards	Wood solid
Syll	Wood solid
Tar paper	Wood products
Coke ash	Copper/other
Sawdust	Wood products
Sawdust lime peat mixed	Wood products, Stone

Wood wool	Wood products
R concrete slab	Concrete
Sand	Sand
Plaster	Concrete
Brick	Clay
Lime gravel	Stone
Concrete	Concrete
Steel bar	Iron/steel
Reinforced concrete	Concrete
Seagrass mat	Copper/other
Reinforced slab	Concrete, iron/steel
Concrete slab	Concrete
Particle board	Wood products
Wood beams	Wood solid
Sawdust	Wood products
Sawdust lime peat mixed	Wood products, Stone
Floorboards	Wood solid
Syll	Wood solid
Panel	Wood solid
Insulation	Foam insulation
Concrete floor	Concrete
Cellar slab	Concrete
R Concrete	Concrete
Hard mineral wool	Mineral wool
Sand	Sand
Enstrich	Concrete
Brick	Concrete
Concrete	Concrete
Leca	Clay
Plaster	Concrete
Porous fiber board	Wood products
Insulation(foam board)	Polymer
Insulation foam	Foam insulation
Foil	Foam insulation
Wood wool	Wood products
Particle board	Wood products
foundation wall	Stone
Foundation wall ext	Stone
Foundation wall int	Stone

Basement ceiling
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Foundation
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Foundation

Foundation foot	Concrete, sometimes including stone or iron/steel
Foundation edge	Concrete
Cellar wall	Concrete
Insulation wall (wood wool)	Wood products
Cardboard wall	Wood products
Grout	Concrete

Foundation	Foundation slab	Concrete
Foundation	Panel inside	Wood solid
Foundation	Porous fiber board 12mm	Wood products
Foundation	Porous fiber board 19mm	Wood products
Foundation	Insulation cellar slab	Mineral wool
Foundation	Panel cellar slab	Wood solid
Foundation	Cellar slab	Concrete, iron/steel
Foundation	Plaster 5mm	Concrete
Foundation	Foundation wall ext plaster	Concrete
Foundation	Foundation wall ext wood wool	Wood products
Foundation	Foundation wall int plaster	Concrete
Foundation	Foundation wall/foot, wood	Wood solid
Foundation	Foundation foot/ext wall	Concrete
Foundation	Foundation foot/int wall	Concrete
Foundation	Foundation plaster	Concrete
Foundation	Foundation wall int plaster	Concrete
Foundation	Foundation wall int brick	Clay
Foundation	Foundation wall ext ligth weight concrete	Concrete
Windows	Foundation wall ext cell plast	Foam insulation
Windows	Wood	Wood solid
	Glass	Glass

7.2 Categories of building according to CERFA in French regulation for waste and reuse

Table 13 : Building's categories according to the French regulation for building waste; Subcategories highlighted in orange are categories where some elements are usually reused in the French context.

Category		***Subcategory***	
VRD (roads, networks)	**1**	**1.1**	External networks (dry, wet, ducts, etc.)
		1.2	Storage (tanks, basins, etc.)
		1.3	Roads and pavements
Foundations and infrastructures	**2**	**1.4**	Fences
		2.1	Foundation
		2.2	Buried walls and structures (cellar stairs cellar, car park, etc.)
Superstructures - Masonry	**3**	**3.1**	Floors, slabs, balconies
		3.2	Beams
		3.3	Facades

		3.4	Partition walls
		3.5	Columns
		3.6	Masonry staircases and banisters
Roofing - Waterproofing - Carpentry - Zinc work		**3.7**	Insulation elements
		3.8	Various types of masonry (brick, breeze block, low wall, etc.)
Partitions - Lining - Suspended suspended ceilings - Interior joinery		**4.1**	Flat roofs
		4.2	Pitched roofs (tiles, slates, etc.)
	4	**4.3**	Technical roof elements
	5	**5.1**	Partitions
		5.2	Wall lining, protective materials insulation and membranes
Façades and exterior joinery		**5.3**	Suspended ceilings
		5.4	Raised floors
		5.5	Interior joinery
		5.6	Metalwork and hardware
	6	**6.1**	Cladding, insulation and lining exterior
Floor coverings, walls and ceilings - Screeds - Paints - Decoration decoration products		**6.2**	Doors, windows, closures, sun protection solar protection
		6.3	Cladding and frames
	7	**7.1**	Floor coverings (parquet, tiles, carpeting, linoleum, etc.)
HVAC (Heating - Ventilation - Air Conditioning)		**7.2**	Wall and ceiling coverings
		7.3	Decorative elements and coverings for joinery
	8	**8.1**	Heating equipment (boilers, water radiators, electric radiators, etc.)
		8.2	Ventilation equipment (AHUs, indoor units units, air vents, etc.)
		8.3	Air conditioning equipment (chillers, cassettes, etc.)
Sanitary installations	**9 10**	**9.1**	Domestic hot water production (DHW DHW, etc.)

		9.2	Indoor distribution and drainage
		9.3	Sanitary appliances (washbasins, WCs, waste basins, urinals, basins, sinks, mixer taps, etc.) urinals, basins, sinks, mixer taps, etc.)
		9.4	Sprinkler systems and networks
Networks		**10.1**	Low-voltage switchboards and cabinets cabinets
		10.2	Electrical distribution (cabling, cable trays cable trays, IT and telephone telephone networks, etc.)
		10.3	Lighting equipment
		10.4	Terminal equipment (switches, sockets, etc.)
		10.5	VDI/IT cabinets
		10.6	Specific equipment (cameras, Wi-Fi terminals, BMS equipment, access controls etc.)
		10.7	Security systems
		10.8	Miscellaneous special equipment
		11.1	Interior furnishings
Furniture		**11.2**	Outdoor furniture
		11.3	Equipment
		11.4	Other
Lifting equipment and other transport equipment	**11**	**12.1**	Lifts
		12.2	Freight elevators
	12	**12.3**	Escalators
Equipment for local electricity production	**13**	**13.1**	Generator sets
Other	**14**	**14.1**	Other