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Energy retrofit scenarios: material flows and circularity

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Abstract. Cities are fast growing and are becoming more and more dependent on external services and supplies to meet their demands. In this context, the building industry can play a major role to reach European and regional targets of low-energy construction and circular design, particularly if considering the need of improving the energy standards and performance of the existing stock. On these premises, this paper presents the findings from recent research and discusses upcoming challenges, in particular: what are the consequences of retrofit operations on material flows, and their impact on circularity and low carbon objectives? In other words, which energy retrofit strategies are being implemented in buildings that could contribute to the production of building' waste or secondary resources today, but also in the future? The purpose of this paper is to analyse the impact of different retrofitting scenarios on the energy performance of material flows. These scenarios can directly influence the nature and quantity of the materials used (inflows) and discarded (outflows) by upgrading or renewing the existing building stock. They can also lead to different environmental impacts and vary the embodied potential (through reuse or recycling) of resources. The analysis focuses on selected case studies representative of the housing stock in Brussels (Belgium). The overall objective is to inform, sensitize, and lead various stakeholders to responsible and conscious choices when retrofitting a building by adding concerns of resources efficiency while focusing on reducing energy demands.

Keywords: energy retrofit scenarios, material flows analysis, urban mining, circular economy, resource efficiency

1. Introduction

Belgium, as most of the European Union, is characterised by an existing building stock that is both old and energy-demand intensive. This context has led Europe to adopt several directives on the energy performance of buildings. These have been implemented in Belgium under the banner of EPB regulations. Since the energy retrofit of existing buildings has become necessary to address ongoing environmental concerns, this also has an influence on the use of materials and the production of waste. The construction sector as a whole is already responsible for a large part of the waste generation and the consumption of raw materials. The current needs of energy retrofit still increase the pressure on the extraction of raw materials and on the environmental impacts. Moreover, in an urban mining perspective, it also influences the stock of materials stored in buildings.

New concerns are arising to face the challenges related to the use of natural resources and the production of waste: circular economy is now a broadly used concept even if it is not yet subject to any regulatory measure. Urban mining is presently considered as an alternative to the depletion of natural resources and our dependence on external supplies. Cities are actually full of potentially valuable materials. These are already on-site and can be reused or recycled for local needs, saving natural resources and lowering environmental impacts due, for example, to reduced needs of transportation (among other things). In Belgium, and especially in the Brussels Capital Region, new objectives of circular economy have been described in a regional programme [1] and some financial incentives have been proposed to support the practical implementation of circular principles. Looking at or treating waste as a valuable material is now rapidly growing and can provide sustainable growth and new employment.

However, despite this awareness, principles of circular economy are often disconnected from energy concerns. To reach more circularity in cities, and especially in the construction sector, a good knowledge of the material stock implemented in buildings is needed [2]. Recently, Urban Metabolism studies have increasingly been conducted to assess cities towards a more resource-efficient urban development [3]. In particular, the study, based on a top-down approach, carried out on the Brussels Capital Region in 2015 has shown a lack of data regarding the building stock [4]. However this study didn’t question the material flows generated by retrofit processes.

In this context, this paper aims to identify the impacts of energy retrofit strategies on material stocks and flows at the building scale. It promotes a bottom-up approach: based on a specific case studies from previous building type analysis, various energy retrofit scenarios on the walls envelope are developed and quantified in terms of material consumption (inflows) and waste production (outflows). This approach allows better knowledge of the building material stock and, especially information about key materials flows (current and to come) that must be managed in a short and long term. This proposal should be seen as complementary to the assessment methods commonly available. The goal is to enhance awareness, knowledge and understanding of energy performance strategies and of their repercussion on material consumption and waste. The overall objective is to lead regions, cities (in this case, the Brussels Capital Region), and all the actors of the construction sector, to apply better and more “responsible” renovation policies and strategies.

2. Methodology

The overall methodology proposed for the study of material balances presented in this paper is shown in Figure 1. The first stage consists of an analysis of the built environment (especially, buildings) and a classification by building type according to construction period, end-use, and location [5]. Three main building types have been selected and categorized based on their year of construction: houses (before 1945), apartment buildings (two periods: before 1945 and between 1945 and 1975) and offices (after 1945). They represent about 70% of the brussels built area (total floor area of buildings) [5]. The second step is to identify typical buildings (called case studies) within these categories, collecting the relative information and sizing the existing stock. Based on the previous phases, energy renovation scenarios are then developed specifically for each building type. To figure out how these various scenarios can affect material stocks and flows, a material balance is then performed: for each scenario, the in- and outflows are grouped by their nature and measured in volume and weight [6]. The final objective is to develop a tool that can simulate and evaluate the impact of these results at the regional level through the application of ratios and the representation of each type within the region.

This paper focusses only on the third and fourth part – energy retrofit scenarios and first material balance results – considering a specific typical case for Brussels: the “Maison Bourgeoise” built before 1945. This building type represents around 60% of the total residential building stock in Brussels (in terms of number of residential buildings) [5].

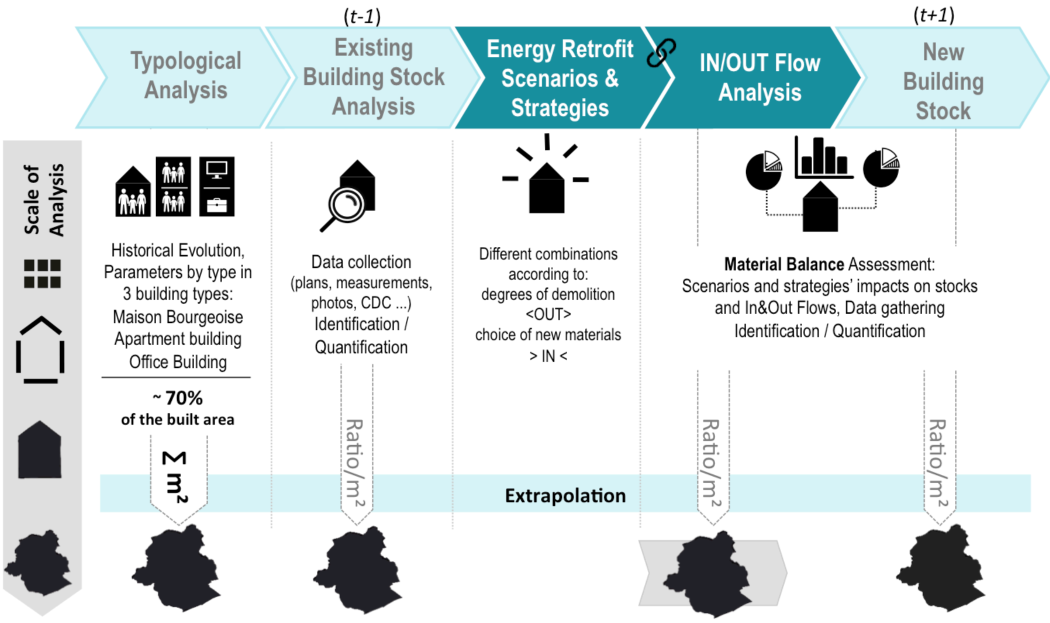


Figure 1. General methodology followed by the research project.

3. Development of Energy retrofit Scenarios: wall scale

Energy retrofit scenarios were proposed based on three case studies coming from building types analysis. Those case studies are houses representative enough of the type "Maison bourgeoise". Preliminary research steps were conducted before developing these energy retrofit scenarios: brussels built stock analysis, definition of building types, selection of case studies, detailed analysis of each case study, etc. Based on case studies and component analysis, different energy retrofit scenarios were then developed for each envelope wall (facades, roofs, floor slabs). These scenarios are advanced on the basis of multiple references [7] and observations coming from the professional practices, data from the call for proposal "Exemplary Buildings" and Brussels Environment (BE) [8]. They were then discussed with different experts in building energy retrofit [9] and heritage. Interior walls and organisation into flats are not included in this study even if these aspects are relevant to issues related to urban densification. Scenarios are developed in two steps as follows:

- 3 options for demolition are considered (minimum demolition, intermediate demolition and maximum demolition) for each envelope wall: demolition degrees are proposed by construction layer of wall, they are then combined within the wall. They will influence the outflows;
- 2 different approaches are then implemented regarding the choice of materials depending on the degree of demolition implemented. This second phase consists in proposing new material solutions to achieve a better energy performance. Two possibilities are offered here: a choice of materials called "classic" and a more "alternative" choice. The first possibility reflects what is commonly, or more generally, implemented today. The second proposes, whenever possible, bio-sourced materials or more reversible solutions (considering classical/known construction techniques and products). This second part will influence the inflows (and to a lesser extend the outflows regarding the waste produced by the implementation).

In total, a maximum of 6 different scenarios per element of the envelope (walls, windows, roofs and slab) are proposed. The figure below presents the different possibilities of scenarios (Figure 2).

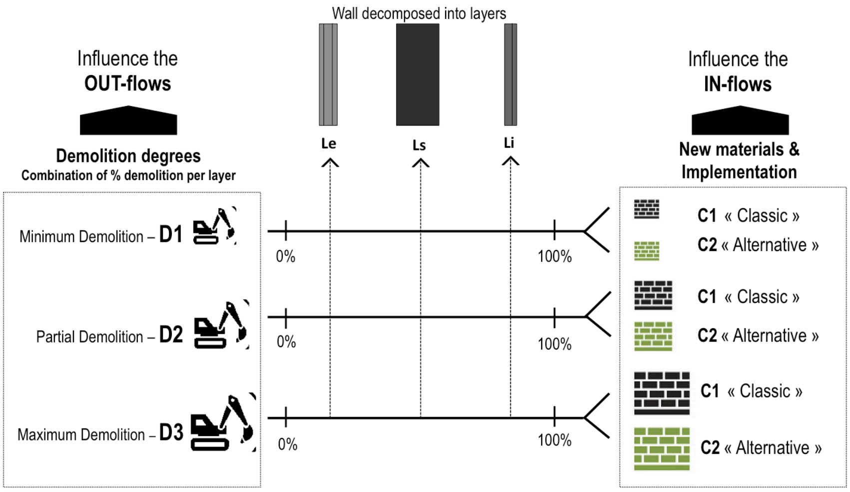


Figure 2. Principles followed for the development of scenarios (A combination of 3 demolition degrees per layer and 2 options for new material implementation).

As mentioned, building are deconstructed into elements, walls, layers and materials. The combination of the degrees of demolition are proposed at the scale of the wall. For the envelope, eleven different walls are identified in the "Maison Bourgeoise" type: façades (front and rear including their windows), roofs (pitched and flat including windows), slab (on cellar and ground floor), gable walls, and annex to the house. This results in 54 improved wall solutions (Figure 3). In order to allow comparisons, it is important to mention that all the improved solutions per wall type offer the same value of thermal resistance.

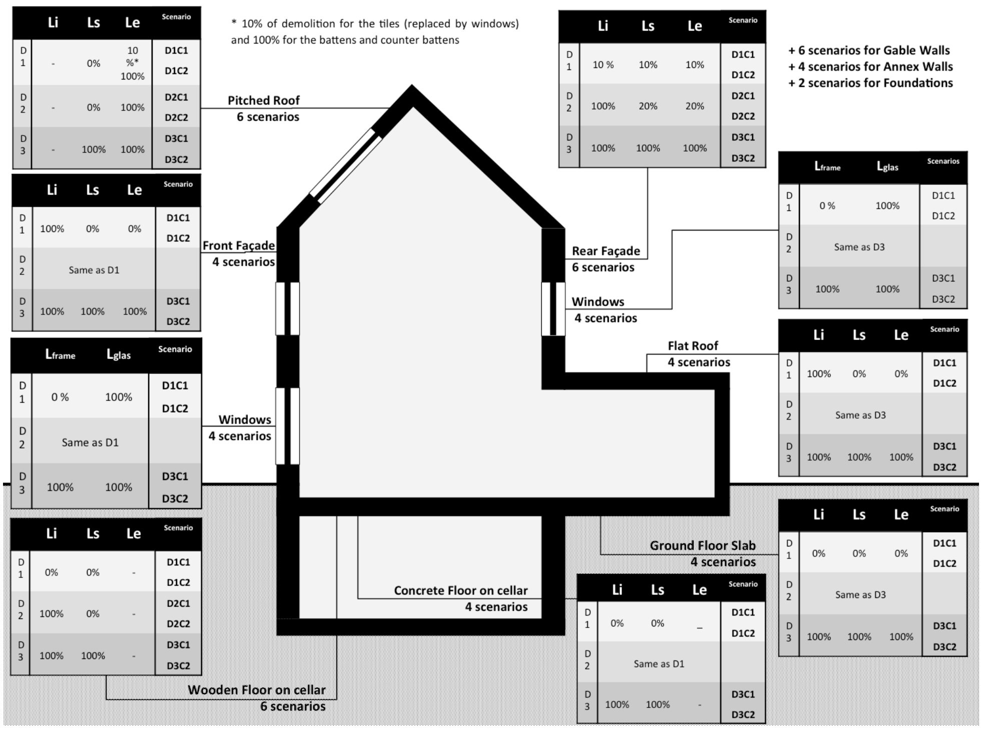


Figure 3. Demolition degrees per layer for each wall type of the envelope.

As an example, various possibilities of energy retrofit for the wall of the rear façade are detailed below. The wall component materials are detailed and grouped by layer (Le, Ls, Li) on which various degrees of demolition are applied. In total, 3 demolition options are considered, 2 different approaches are implemented regarding the choice of materials, resulting in six different energy retrofit scenarios (Figure 4). All solutions have the same thermal resistance to allow comparisons.

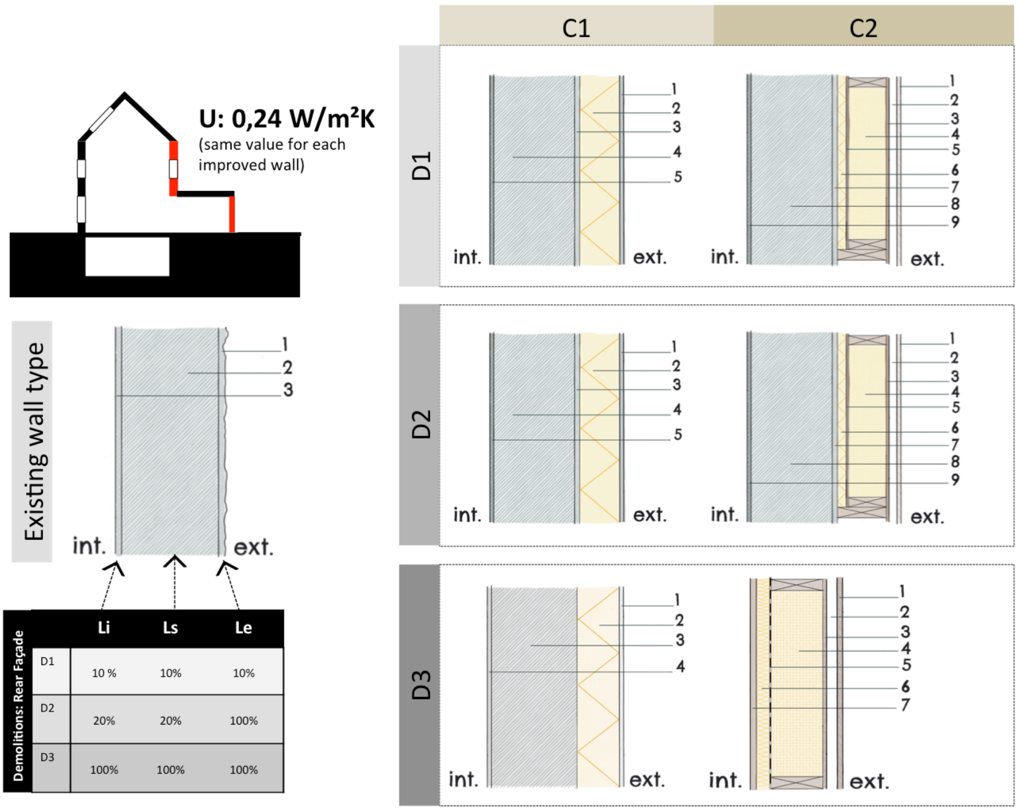


Figure 4. Rear façade: the 6 different scenarios to improve energy efficiency of the wall.

The wall retrofit options presented here illustrate the work done for each wall of the envelope: same approach are developed for roofs, slabs and windows. It is also important to note that energy retrofit solutions apply at different levels: scenarios are first developed at the scale of the wall and its constituent elements as illustrated in Figure 4 (called *energy retrofit scenarios*), then different combinations of intervention are possible at the scale of the building also called *energy retrofit strategies* (as illustrated in Figures 5 and 6). This part is described in the following paragraphs. Each of these energy retrofit solutions (scenarios and strategies) have a different impact in terms of material consumption and waste production, while also having different environmental impacts and potential for reuse.

4. Impacts on Material stocks and flows: building scale

Once the scenarios are determined, material balance can be applied with different wall combinations to produce results at the building scale. All buildings materials are counted in volume and weight for the entire building based on 3 distinct phases; before, during, and after renovation. This corresponds to the existing building stock, the in- and outflows and the new building stock after retrofitting. This analysis brings forward the impact of the different energy retrofit scenarios and strategies on material stocks and allows a comparison between different improvement options in terms of material flows. In the following paragraph, two different energy retrofit strategies are compared on a case study “Maison Bourgeoise” from 1900 to illustrate the process. The methodology that the authors developed gives the opportunity to choose the strategy adopted by wall and then results are generated at the scale of the building.

4.1. Material Balance on a Bourgeois House from 1900

To illustrate the followed method, the authors opted for 2 opposite energy retrofit strategies: D1 corresponds to a minimum of demolition and D3 includes a maximum demolition. For all wall types, the scenario C1 is selected: it corresponds to “classical” solutions and material choices. However each wall can adopt separate scenario if desired, thus allowing for multiple combinations of interventions (Figure 5 and Figure 6).

SCENARIO X (m^3)	
Front Facade	D1C1
Rear Facade	D1C1
Shared Wall (left gable)	D1C1
Shared Wall (right gable)	D1C1
Annex Walls	D1C1
Windows	D1C1
Pitched Roof	D1C1
Flat Roof (Annex)	D1C1
Ground Floor Slab	D1C1
Foundation	D1C1

choice to operate by wall type between the six possible scenarios

Figure 5. Scenario X: minimum demolition

SCENARIO Z (m^3)	
Front Facade	D3C1
Rear Facade	D3C1
Shared Wall (left gable)	D3C1
Shared Wall (right gable)	D3C1
Annex Walls	D3C1
Windows	D3C1
Pitched Roof	D3C1
Flat Roof (Annex)	D3C1
Ground Floor Slab	D3C1
Foundation	D3C1

choice to operate by wall type between the six possible scenarios

Figure 6. Scenario Z: maximum demolition

The results in volume of these two strategies for the entire building envelope are showed in the figures below (Figure 7 and Figure 8). For each scenario chart, the bar on the left shows the initial existing stock, the one on the right the new stock after renovation. The second column of the graph presents the outflows, and the third, lists the inflows. The first scenario (X) generates a flow of 59 m^3 of building materials (in and outflows combined), while the second scenario (Z) produces almost six times more (340m^3). In terms of weight, the difference is even more significant: demolition (scenario Z) mobilizes almost 15 times more material than the first option (scenario X). So, for the same energy performance of walls, the potential saving of material between the two scenarios corresponds to a volume of 281m^3, or a weight of 404 tons (Table 1). These are mainly distributed between: inert waste, wood and lime for the outflows and insulation, inert materials and gypsum concerning the inflows. It is important to note that outflows are also considered the waste produced by material implementation during the renovation process (between 1 and 5% depending on the type of material). Which explains that outflows appear for material that does not appear in the initial stock (example of the insulating fraction for scenario X).

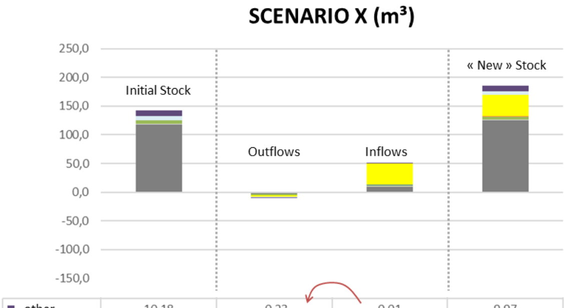
Table 1. Results in volume and weight for the two scenarios at the building scale.

	Volume [m^3]		Weight [t]	
Scenarios	X	Z	X	Z
∑Outflows	9	143	1,880	247,338
∑Inflows	50	196	26,272	184,967
∑Total Flows	59	339	28,152	459,305
Difference Δ	280		431,153	
Multiplicative factor	6		15	

Concerning the outflows, a quick calculation shows a saving of 2981 $kgCO_2$equ./tkm in terms of transport (considering a 40 tons truck) between the two scenarios (in favour of scenario X: maximum conservation). This result is calculated based on different references: Ecosoft for the global warming potential depending on the mode of transportation (0,15 $kgCO_2$equ./tkm for a 40 tons truck) and MMG studies for transportation distances [10]:

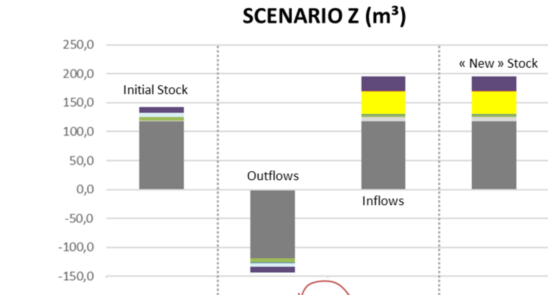
- 30 km from demolition site to sorting facility or collection point;
- 50 km from sorting facility or collection point to landfill;
- 100 km from sorting facility or collection point to incinerator.

The economy generated by the first scenario solution (X) is even greater if we consider the embodied energy of the new materials used (much more important in the case of scenario Z).



other	10,18	-0,23	0,01	9,97
lime	6,636276195	-1,0738044	0	5,56
cement fiber	0	0	0	0,00
composite	0	0	0	0,00
insulation	0	-1,853985328	37,07970655	37,08
plastic	0,1388172	-0,009394059	0,562946171	0,70
metal	0,32166592	0,00	0,30882096	0,63
wood	6,6	-3,224178499	1,56	5,02
gypsum	0,0	-0,13	1,640175	1,64
inert	118,4	-2,50	8,86	124,86

Figure 7. Results for scenario X in volume.



other	10,18	-10,18	24,89	24,89
lime	6,636276195	-6,636276195	0	0,00
cement fiber	0	0	0	0,00
composite	0	0	1,15191455	1,15
insulation	0	-0,00174875	39,83624333	39,84
plastic	0,1388172	-0,46393131	0,9899921	0,99
metal	0,32166592	-0,32	0,63048688	0,63
wood	6,6	-7,142824011	3,72	3,72
gypsum	0,0	-0,24	7,123976195	7,12
inert	118,4	-118,80	117,53	117,53

Figure 8. Results for scenario Z in volume.

This is an example of results that can be generated. The advantage of the method developed lies in the fact that different scenarios and strategies can be simulated: comparison between conventional and alternative techniques, various degrees of demolition, etc. The overall objective is to raise awareness and inform building stakeholders about the impact of their choice to improve energy performance on the consumption of materials and the production of waste.

5. Conclusions and outlooks

This paper provides some of the answers to better characterise and evaluate the impact of various energy retrofit solutions on building materials stocks and flows. The methodology and its application to case studies present a great potential in terms of material stocks and flows management (towards urban mining) at different scales (walls / building / region). Indeed, it aims to anticipate the possible building materials stocks and flows generated by the energy retrofit of the Brussel's building stock and thus, lead to achieve a more circular economy.

However, the wall types and intervention scenario approach is not exhaustive, as in many cases each building is different. Nevertheless, trends can be identified: it makes it possible to simulate a certain number of cases according to 3 types of buildings quite distinct and fairly representative in the Brussels region (this article focuses on the "Maison Bourgeoise"). By opting for the analysis of these built types, a certain reproducibility in the principles of intervention is aimed at. To this end, grouping by type (type of building, typical walls, renovation scenario, etc.) tends to 'simplify' the model, already particularly large and complex, and to categorize a series of intervention options. This approach makes it possible to generate first results of the impacts of energy renovation on matter (stocks, in-and outflows).

Furthermore, additional work related to the generation of results, data and complementary analysis is necessary to enable the implementation of an effective resource management tool at the regional level. The research work will continue in the future to deepen the knowledge of the material deposit contained in buildings and energy retrofit impacts on material flows through:

- Extension of the analysis methodology to other case studies including other Brussel's building types (offices and apartment buildings built after 1945): development of specific intervention scenarios, analysis of the material balance and impacts of the interventions on material stocks and flows.
- Extrapolation of results at the regional level (in an urban mining perspective) based on the cadastral matrix.

This can move us forward to a more circular economy as advocated by the Brussels-Capital Region and correlates with the principles of urban mining.

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