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Influence of energy retrofit on material flows: comparison between various strategies

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Abstract. Cities are fast growing and their dependence on external services and supplies increases with time. In Europe, the existing building stock is both ageing and energy-demand intensive: its energy retrofit becomes necessary, this resulting in waste generation and pressure on the availability of raw materials. New approaches such as circular economy are arising to face these challenges. However, principles of circular economy are not necessarily associated with energy concerns. To address this gap, this paper considers the current need of retrofit strategies in an urban mining perspective. A methodology based on a bottom-up approach is proposed, aiming to evaluate the impacts of energy retrofit strategies on material stocks and flows at the building scale.

1. Introduction

Cities are fast growing and their dependence on external services and supplies to meet their demands increases with time. In Europe, a particularly important role within this process is played by the existing building stock, which is both ageing and energy-demand intensive. This context has led European countries to adopt several directives on the energy performance of buildings. Since the energy retrofit of existing buildings becomes necessary to address ongoing environmental concerns, this is also increasing the generation of waste and intensifying the pressure on the extraction and availability of raw materials. To this aim, new concepts such as circular economy are emerging to deal with resource and waste issues, even if these are not yet subject to any regulatory measure. In Belgium, especially in the Brussels-Capital Region, the circular economy is gradually introduced into the strategies and objectives pursued [1].

However, principles of circular economy are not necessarily associated with energy concerns and vice-versa. Conversely, some solutions that improve energy performance could even contrast with circular design principles in terms of, for example, choice of materials and construction techniques. To provide long-term solutions addressing environmental issues, it is thus necessary to approach energy retrofit operations from the angle of circularity. Various complementary principles are possible according to this precept: adaptability, flexibility, compatibility and reversibility at different scales allowing reuse of the building, components or materials, today but also in the future. These considerations relate to the design phase. Another important dimension to reach more circularity in the construction sector relates to the need and accessibility of reliable and convenient data on materials and their potential to be reintroduced into appropriate cycles. Therefore, material passports provides a real opportunity in terms of information gathering, but it is no less in a proposal state and above all is hardly



feasible considering the existing building stock. Furthermore, a proper knowledge of the material stock implemented in existing buildings is necessary. In this perspective, recent urban metabolism studies have attempted to assess cities towards a more resource-efficient urban development. Nevertheless, these studies – which were mainly based on top-down approaches – have generally resulted in inconclusive information regarding the building stock, without effectively questioning the material flows generated by retrofit processes [2].

In response to this gap, this paper aims to address the current need of retrofit strategies in an urban mining and circular perspective. A methodology based on a bottom-up approach has been developed [3], proposing to evaluate the impacts of energy retrofit strategies on material stocks and flows at the building scale and in a specific context: the Brussels-Capital Region. The goal is to enhance awareness, knowledge and understanding of the repercussions of energy performance strategies on material consumption and waste.

2. Methodology

The methodology is based on a bottom-up approach that can respond complementary in a complementary way to existing top-down strategies within the Brussels-Capital Region [2] [3]. This approach aims to produce more precise data on the material stocked in existing buildings. This will allow developing framework for different intervention scenarios considering the need for energy retrofitting. These scenarios are combined to develop global energy retrofit strategies at the building scale. They are then quantified in terms of material consumption (in-flows) and waste production (out-flows). This methodology provides a more comprehensive knowledge of the building material stock and allows comparisons between different energy strategies in terms of material flows (type and quantities) and their environmental impacts. Information about key materials flows and their embodied energy and carbon that must be managed in a short and long term is also presented. The methodology and its application to a selection of case studies in Brussels presents a great potential for the Brussels's Capital Region but can also be transferred to other cities and regions. Indeed, it aims to anticipate the possible building materials stocks and flows generated by the energy retrofit of the existing building and, thus, leads towards a more circular economy by applying better renovation policies and strategies.

The methodology has been defined based on several steps that are described below:

- A typological analysis was first conducted to study the evolution of the Brussels building stock considering the two main end-use functions (housing and offices): this included study of urban development, implantation, morphology, construction techniques, and composition. This led to a classification by building type according to construction period, end-use, and location [4].
- A typical building, considered adequately representative for Brussels, was then selected, followed by the analysis of some case studies. This step included data gathering, processing of information, and the decomposition of the building into standard wall types, layers and components materials [5] [6]. This corresponded to the characterization of the building stock.
- Various energy retrofit scenarios were developed based on the previously-defined wall types from the case studies. For each wall type, a maximum of 6 different improved scenarios were proposed with the same thermal properties. The development of these scenarios is described in the following sections of this paper.
- Once the scenarios had been determined, material balance [5] [6] could be applied with different wall combinations to produce results at the building scale. These are defined as energy retrofit strategies and count materials (stock and flows) in volume and weight in three distinct states: initial material stock, in- and out-flows produced by the retrofitting, and the new material stock after retrofit. The comparison of energy retrofit strategies and their impact on the material balance is discussed in the following sections.

2.1. Focus on the Type “Maison Bourgeoise”

The typological analysis highlighted three main types of building present on the Brussels area:

- Family houses (mainly built before 1945) also called “Maison Bourgeoise” type;

- Apartment buildings (two periods: built before 1945 and built between 1945 and 1975);
- Offices (mainly built after 1945).

Together, they compose almost 70% of the built surface (total floor area of buildings) in Brussels [5]. The case studies to be analysed were then chosen within these categories. The upgraded scenarios were defined specifically for each building type [4] [7].

The scenarios described below focus on the “Maison Bourgeoise” type as it corresponds to 39% of the housing stock in terms of numbers of buildings [4]. All energy retrofit solutions were developed regarding this kind of construction.

2.2. Energy retrofit scenarios: principles

As mentioned above, due to the age of an important part of the building stock, one of the major issues in Brussels (as in most European cities) consists in reducing energy use during building occupancy. Among others solutions, an intervention to improve the performance of the envelope is therefore required. The scenarios described below focus specifically on enhancing the energy performance of the envelope walls. Depending on the type of building and wall, different options are possible. Internal remodelling, volume increase or apartment division were not considered in this study even if they partly meet the urban and densification challenge of the region. The development of the scenario is based on the following principles (Figure 1):

- 3 alternatives for demolition are proposed (from minimum “D1” to maximum demolition “D3”) for each envelope wall: this results from a combination of varying degrees of demolition applied to the constituent layers of the wall. These choices affect the out-flows.
- 2 types of options are evaluated for the new materials to be used considering the degree of demolition previously chosen. The first choice “C1” is based on common practice. The second choice “C2” represents a more ‘alternative’ choice: bio-sourced materials or more reversible solutions whenever possible. These options affect the in-flows (and a small part of the outflows considering the waste generated by their implementation).
- In total, a maximum of 6 different scenarios per element of the envelope (walls, windows, roofs and slab) are proposed: D1C1, D1C2, D2C1, D2C2, D3C1, and D3C2.

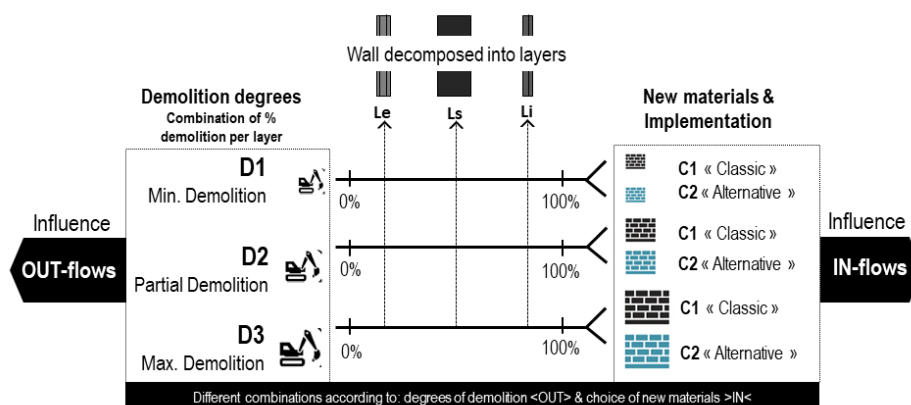


Figure 1. Energy retrofit scenarios: principles

2.3. Energy retrofit scenarios by wall type

The characterization of the wall types of the “Maison Bourgeoise”, and the specific upgraded solutions developed for each of them (even their combination in the building scale retrofit strategy), are based on numerous sources: previous research projects and publications (B3Retrotool, Energie+ decision support tool, urban metabolism studies, etc.); Technical Information Notes and Technical datasheets; feedback from the Brussel’s call for proposal “Be Exemplary” and “Be.Circular”; discussion and meetings with several actors and experts in Energy Performance of Buildings (EPB) and heritage. For each wall type,

all the upgraded wall solutions present the same thermal properties (U-value) and are based considering the previous scenario principles. Eleven wall types were selected for the case of the “Maison Bourgeoise”: façades (front and rear including their windows), roofs (pitched and flat including windows), slabs (on cellar and ground floor), gable walls, and annexes to the house (Figure 2).

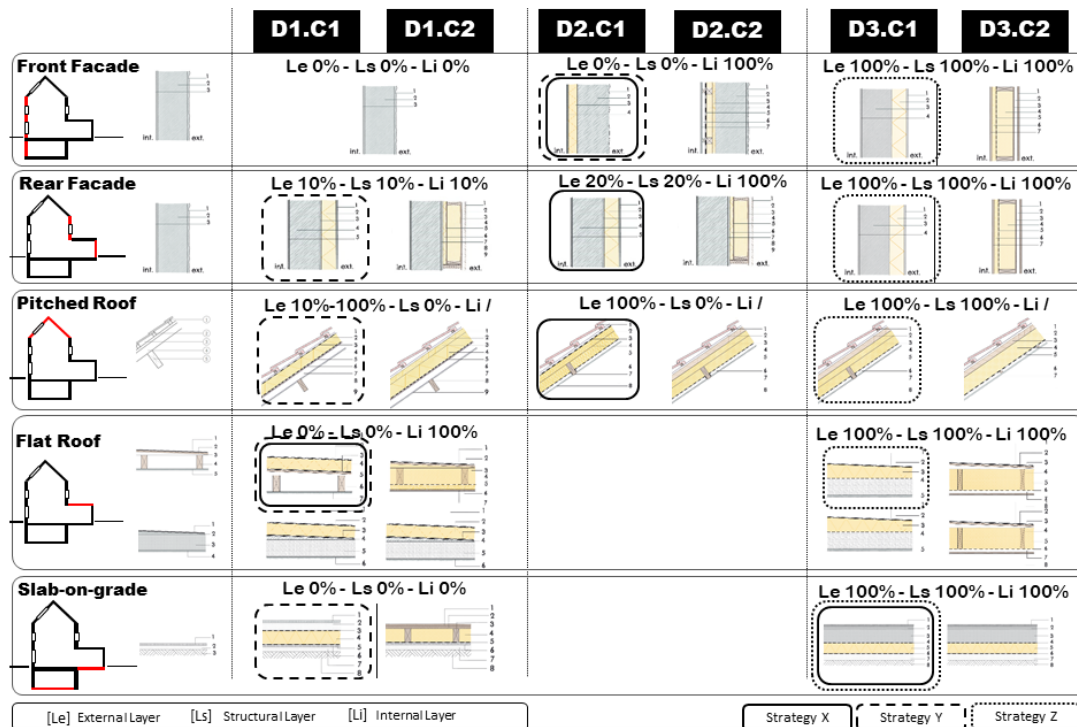


Figure 2. Improved wall solutions for the envelope and their 3 combinations

2.4. Energy retrofit strategies: combination of upgraded scenarios at a building scale

The next step of the analysis (energy retrofit strategies) relates to different wall combinations (based on the previous scenarios) that can be chosen to produce results at the building scale. The material balance tool we developed for this purpose allows a comparison between 3 different strategies. Results are presented in volume and weight and considers 3 distinct stages: before renovation (existing stock), during renovation (in- and out-flows) and after renovation (new material stock). This 3-step analysis provides the impact of the different energy retrofit strategies on material stocks and flows.

The three energy retrofit strategies to be compared were determined as follows (Figure 2):

- First strategy (X): combination of most common improved walls (based on the same sources used for scenario development) > framed in continuous line _____
- Second strategy (Y): strategy X considering the minimum demolition option (D1) for all improved walls > framed in broken lines - - - - -
- Third strategy (Z): strategy X considering the maximum demolition option (D3) for all improved walls > framed in dotted line

3. Results

As expected, existing material stocks are mainly composed by inert materials, especially old bricks, as they are typical of the construction techniques of the period: the share of inert components corresponds to 88% in weight (284.18 tons) and 83% in volume. The distribution of materials after renovation does not vary significantly in weight: around 86% for inert materials for the three energy retrofit strategies, the proportion of other fractions (gypsum, metal, synthetics and insulation) having increased very slightly. The distribution is significantly different in terms of volume. The second largest fraction of

material is insulation (from 16% to 25% in volume depending on the strategy) whereas this represents less than 1% by weight. In this context, it must be considered that the “Maison Bourgeoise” is a standard townhouse with only two insulated facades; of course, this share would be more substantial in detached houses and apartment building. Other large shares correspond to gypsum and wood (Figure 3).

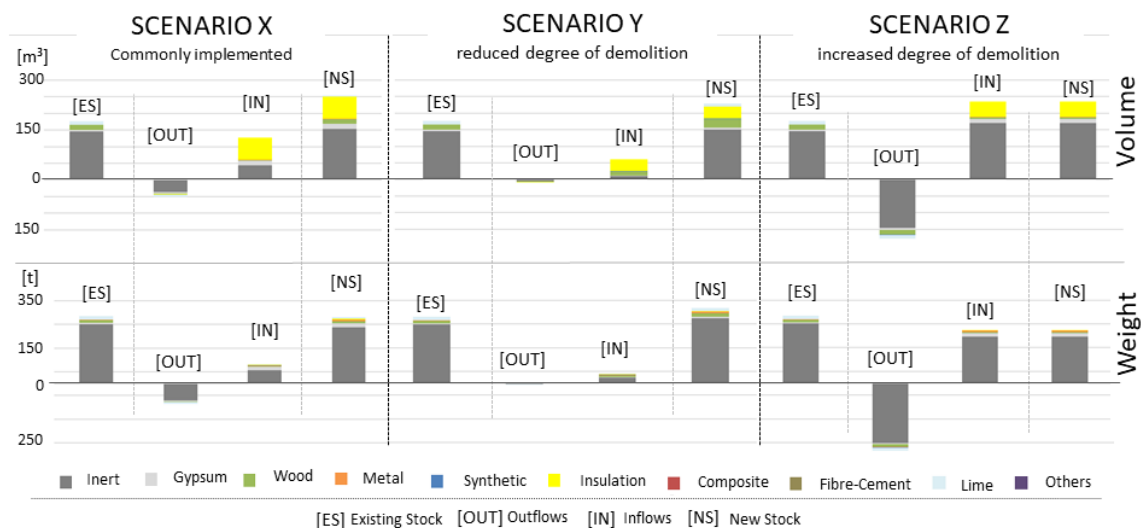


Figure 3. Material balance regarding the 3 various energy retrofit strategies

In any case, the retrofitting strategies increase the total volume of materials contained in the building (from 52 to 77 m³ extra). This is of course due to the addition of materials in order to improve the thermal performance of the building. On the other hand, in terms of weight, this tendency is less clear. Because the third strategy (Z-maximum demolition) replace the main heavy materials (old bricks) by hollow blocks, it has a lower total weight. This remark is also valid, but to a lesser extent, for the initial strategy (X), while the total weight of the material stock increases in the case of strategy Y. The strategy Z (maximum demolition) generates nearly 6 times more volume of materials (in and out-flows combined) than the strategy Y (minimum demolition), more than twice the initial strategy (X). Conversely, in terms of weight, strategy Z produces respectively 12 times more than strategy Y and 3 times more than strategy X. Of course, all these material flows set in motion have associated environmental impacts.

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

Scenarios	Volume [m ³]			Weight [t]		
	X	Y	Z	X	Y	Z
Existing Stock		176,1			284,18	
Σ Outflows	-49,7	-9,8	-177,1	-85,81	-4,84	-285,31
Σ Inflows	126,4	61,4	234,2	80,89	37,71	224,06
New Stock	253,9	229,1	234,2	280,3	318,37	224,06
Σ Total Flows	176,1	71,2	411,3	166,7	42,55	509,37
Difference Δ		-104,9	+235,2		-124,15	+342,67
Multiplicative factor		0,404	2,34		0,255	3,06

The out-flows are influenced by two parameters: the existing stock and the degree of demolition implemented. They are therefore mostly composed of inert material (for the most part bricks) and in a much lower proportion of lime, wood and gypsum. Inert wastes are largely recycled in Belgium (up to 95%). Considering 40-ton truck and a distance of 80km (30km from demolition site to collection point and 50km from collection point to treatment center), the transport of the outgoing flows will generate

respectively 2000 kgCO₂e for the initial solution (X), 511 kgCO₂e for the strategy Y and more than 6112 kgCO₂e for the strategy Z. If only considering waste transportation, a saving of 5.6 tons of CO₂ is possible between the strategy X and Z. This CO₂ saving could be even greater considering the impact of the embodied energy for the new materials used (much more important in the case of scenario Z) [8].

Regarding the first 2 strategies (X-Y), more than half of the volume of the inflows concern insulation. For the 3rd strategy (Z), they constitute nearly 20% of the volume. The other important fractions are inert (up to 34% for X, 17% for Y and 73% for Z), wood (20% for Y) and gypsum (12% for X and 5% for Z).

4. Conclusions

As mentioned in the introduction, it is important to improve our knowledge of material flows potentially generated by the energy retrofitting of the housing stock, in order to apply a more circular economy in the construction sector. This article can provide a first attending answer to these issues by comparing and quantifying the impact of various energy retrofit solutions on building materials stocks and flows. The methodology proposed, and its application to actual case studies, present a great potential in terms of management of material stocks and flows. But it also makes it possible to integrate a reflection on the impact of our design choices conciliating energy performances and stakes of the material resources. However, the wall types and intervention scenario approach is not exhaustive, as in many cases each building is different. The overall objective of the bottom-up approach is to identify building-scale trends in order to bring them back to the urban scale. However, further work on the generation of results, data and complementary analysis is still necessary to enable the implementation of an effective resource management tool at the regional level. Future research will continue to deepen the knowledge of the material deposit contained in other building types (offices, apartment building). Specific intervention scenarios will therefore be developed and analysed in terms of material balances.

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