Building as material deposit:
Material balances and "recoverability" into retrofitting processes

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ABSTRACT: The research will address an environmentally important issue, namely the economy and the preservation of resources and the reduction of waste. Given the energy context, the renovation of the old and energy consuming existing building stock appears essential. But the energy retrofit process also generates waste and consumes a certain amount of raw materials. We could say that the issue of reducing the energy consumption of buildings is now well integrated by architects. That same awareness has not yet been applied to resources and waste issues. Moreover, the lack of data concerning the renovation and construction impacts on material stocks and flows represents an obstacle to achieve a closed loop system in which waste is considered as a resource. This research will investigate these issues by studying some energy retrofit interventions in terms of material impacts also referred to as material balances. As wall as recovery potential, also referred to as recoverability. In practice, the study will first identify and quantify the material and waste consumed and generated by the operation (by weight and volume). Secondly it will propose a qualitative assessment to evaluate the recovery potential of as-built and improved walls in order to integrate a reflection on resources possibilities the as-built environment could represent.
Keywords: energy and sustainable retrofit, building materials, construction & demolition waste, material stocks & flows, recovery potential

INTRODUCTION

The European economy consumes a significant amount of resources for its operations, but it also produces a huge amount of waste. Despite increasingly efficient management, this trend continues to grow with devastating consequences for our ecosystems. Furthermore, resource scarcities and the dependency on imported raw materials and energy supplies led the EU to take action for more efficient resource management and a more circular economy. In this context, the construction sector plays a major role since it is responsible for 40 % of the raw materials and energy consumption and for 35% of the waste generation (European Environment Agency, 2010). Moreover, the large existing building stock, mainly represented by dwellings, is quite old and not energy efficient. Due to implementation of new energy efficiency regulations, one of the architect's major concerns is the reduction of energy consumption during the service life of the building. But what about reducing waste and material consumption which are also priorities of sustainable development? These considerations are little known and seldom taken into account by the actors of the construction sector. Furthermore, energy retrofit of the building stock has become necessary to address the current environmental challenges. Retrofits to enhance energy performance of buildings will irremediably influence the material stocks and flows.

In this perspective, this survey aims to confront the current energy retrofit process with the waste and resource issues. What impacts will these upgrades have on material stocks & flows? What are we implementing now that could create waste or potential resources over time? The proposed assumption is to consider the building stock as a material deposit, in other words a source of potentially recoverable materials (materials source). On a larger scale and on a medium or long-term basis, our built environment may represent a potential for local resources. Currently, the data of the material stocks and flows, contained in the housing stock, is incomplete or non-existent, especially for the Brussels Capital Region. However, to reach a more circular economy, which is one of the European Union's main goals, we first have to gain a better knowledge of the material deposit contained in our cities (such as the concept of *urban mining*). This proposal aims to develop a methodology (in a bottom-up approach) to provide a first answer to the lack of data required to achieve a more closed loop system.

METHODOLOGY

To achieve this objective, the proposed methodology takes place in two stages. First of all, the study will analyze the impact of the renovation in terms of material, including new materials consumed, and waste generated (**material balance**). Secondly, it will develop a qualitative assessment to improve the recovery potential of constructed elements (**recoverability)**.

Material balance

In order to determine the implication of the renovation process from a material perspective, the study identifies and quantifies (in weight and volume) the material stocks and flows generated in three different steps: existing stock (before renovation), in and out flows (during renovation) and new material stock (after renovation). To realize this material balance, the study proposes to evaluate case studies chosen for their representativeness at a regional scale (Brussels Capital Region). The analysis is developed in a bottom-up approach: from constitutive components, and materials, to the all building. This methodology allows prospective extrapolations of the material deposits and flows generated at a larger scale (urban area) that is not treated in this paper. It concerns a second study funded through a European Fund for Regional Economic Development for Brussels that has just begun. In Brussels, the residential sector represents about 60% of the existing building stock and more than a half of the housing stock was built before World War II (Athanassiadis, 2014). We concentrated our search on this type of building. The case study therefore treated is as an energy retrofit of a residential building built before 1945 in the Brussels Capital Region. The analysis focused on envelope components, and internal partitioning walls and floors. Service's (electricity, plumbing and sanitary installations, heating and ventilation system…) and internal finishes such as paints, varnishes, oil and other coatings are not included in this study.

Regarding the identification, the researcher organizes the different material fractions into several groups depending on their nature: inert materials, mineral binders, wood and derivatives, metals, plastic materials and derivatives, glass, and insulation materials. As we studied existing buildings in a dense urban area, we didn't consider soil in the identified fractions. Even if insulation materials are of different natures (some are organic or inorganic, some are derivatives of plastic materials…), the author decided to consider them as a specific category or fraction; these materials have indeed a particular status in energy performances of buildings.

The quantification is based on building plan, a bill of material, specifications and site visits. It has been led in three steps and two units. It measures the existing stock (before renovation), the new stock (after energy retrofit), the in and out flows (new materials and waste) generated by the operation. As a matter of fact, the type of energy retrofit will affect the in and out flows and significantly influence the future material deposit contained in the building stock. The reason the analysis was made in three stages (before, during and after) is so we can evaluate the effect of the renovation on material flows and stocks (Fig. 1). The quantification has been conducted in weight and volume as the ton is the common unit used in the waste sector and the cubic meter is more coherent and used by architects. The objective of this double measurement is also to highlight if significant differences appear in the results between the two units.

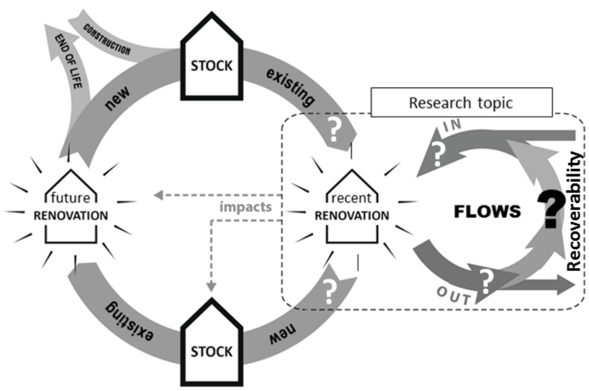

Figure 1: Proposed Methodology in two stages: Material balance in three steps (before, during and after energy retrofit), and recoverability assessment.

Recoverability

Knowing the flows generated by retrofit operation and the deposits contained in our cities is essential to better management of resources. Even if quantification is an important preliminary stage in this case, it doesn't tell about the recovery potentialities of built elements. The research therefore develops a qualitative assessment to determine the material potential contained within the identified stocks to be recovered. This qualitative assessment is referred to as **recoverability**. This evaluation also creates awareness among designers in relation to the impact of their materials and implementation choices on the future recovery value.

The assessment of the recoverability is conducted on different wall types of the envelope: one existing wall type per envelope component (roof, façade, floor tile) and two to four improved solutions for each existing wall type (Fig. 2: example for façade wall). For improved walls, two approaches are treated:

- the existing wall is preserved and improved (named *exist+* or *exist++*) or
- the existing wall is demolished and rebuilt: in the same way, in terms of wall composition, as the improved solution (named *new//exist+*) or in another way (named *new*).

The wall types are identified from ten case studies similar to the one in the material balance: energy retrofit of Brussels' residential buildings built before 1945.

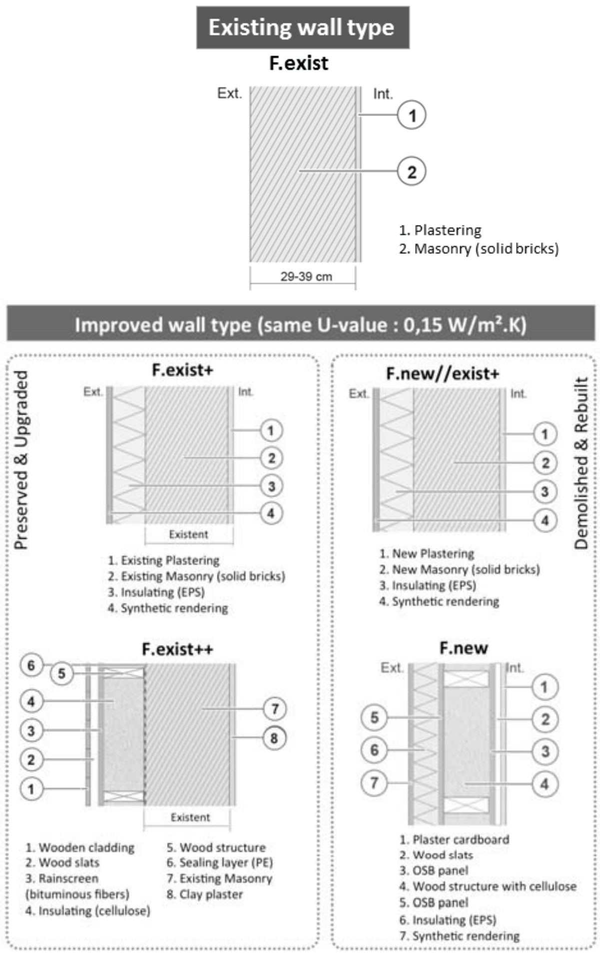

Figure 2: Different wall types analysed (existing and improved): example for the façade

To develop this evaluation, the study first identifies different recovery categories. The survey will thus assess separately the potential of reuse (R^+), the potential of recycling (R), the potential of organic recovery (C for 'composting') and finally the potential of thermal recovery (I for 'incineration'). Based on a literature review (Brand, 1994; Durmisevic, 2006; Gorgolewski, 2008; Nordby, 2009; Paduart, 2012; Sassi, 2004; Vefago, 2013), a list of various parameters influencing these different degrees of recoverability has been established. These parameters are organized and classified depending on the different lifecycle steps they belong to: manufacturing, implementation, service life and end of life (Tab. 1). As it is not a recovery process, prevention is not included in this assessment but it represents a prior step to recovery (according to the European Waste Framework Directive 2008/98/EC). As such, prefabrication, maintenance and numbers of replacement such as compatibility between lifetime and situation in layer are some of the parameters contributing to prevention.

To manage the assessment, the wall type is decomposed into its constitutive materials depending on their respective weight and volume for 1m² of wall. So the recoverability assessment is applied for two units as has been done for the material balance. For each parameter, the wall type will receive a score from 0 (if it does not fulfill the parameter) to 1 (if it completely meets the considered parameter). In total, there are thirteen parameters treated for the reuse potential, six for the recycling potential and respectively one for the organic and thermal recovery potential (Tab. 1). In this evaluation, the author opted for a similar importance for each parameter to limit judgement interpretations (already present in any qualitative assessment). However, some unfulfilled parameters are excluding as they erase some recovery potential: hazardous matter eliminate any type of recovery, irreversible connections annihilate reuse opportunities, and the intrinsic abilities of material to be reused, recycled, composted or burned is also determinant. As the numbers of parameters (and thus score) varies between the different recovery potentials, the results will be presented in percentage.

Table 1: Parameters considered in recoverability assessment organized in different lifecycle stages: R^+ (reuse), R (recycling), C (composting), I (incineration).

Potential of	R^+	R	C	I
manufacturing				
Nature (homogeneous, composite)		X		
Shape	X			
Scale, size, modularity	X			
Repeated use ability	X			
implementation				
Type of assembly	X			
Number of assembly	X			
Constructive system's simplicity	X			
lifetime				
Lifetime	X			
Independence between layers	X	X		
Connection accessibility	X			
end of life				
Number of material fractions from different categories	X	X		
Potential quality of fractions	X	X		
Existence of the sector	X	X		
Ability to be reused	X			
Ability to be recycled		X		
Ability to be composted			X	
Ability to be burned				X
Numbers of parameters				
Total	**13**	**6**	**1**	**1**

RESULTS

For both material balance and recoverability, results are shown into two units (weight and volume).

Material balances

Considering weight, the results ratify inert material as the main fraction in the total construction weight, before but also after the energy retrofit process. It represents a significant part of the outflows too (Fig. 3). Globally, the fraction's ventilation for the existing stock and the new one (renovated) is quite similar. Most of the inflows are represented by wood materials (32%), inert materials (26%), mineral binders (22%) and insulation materials (13%). The findings in terms of volume diverge especially concerning the new stock and the inflows. While inert materials are still the most important part of the outflows and existing stock, insulation materials constitute a third of the stock after renovation and represent more than 80% of the new materials implemented by the retrofit operation.

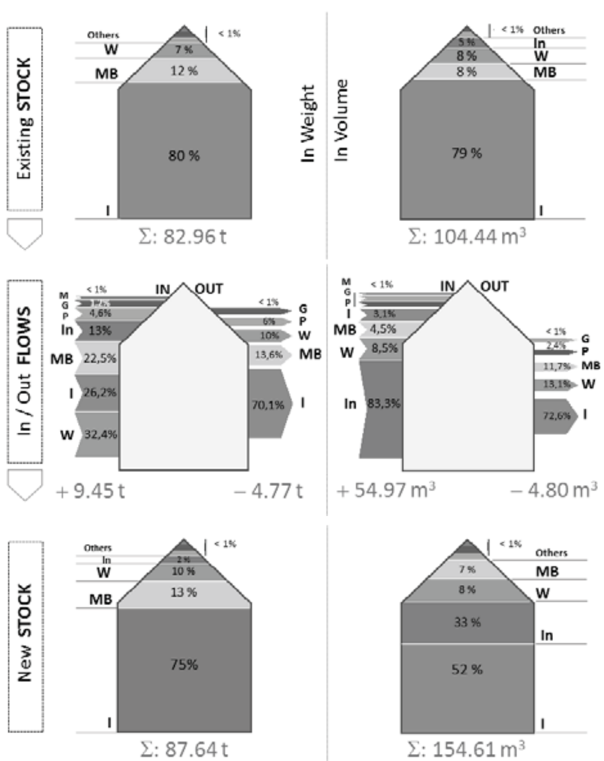

Figure 3: Material Balance in weight (tons) - on the left side - and volume (cubic meters) – on the right side
***I:** Inert; **MB**: Mineral Binders; **W:** Wood; **M**: Metals; **P**: Plastics; **G**: Glass; **In**: Insulation*

Obviously, the differences between the results in weight and volume are due to the disparate densities of the several used materials and their proportion in the building. Nevertheless, comparing these two units points out that inert materials are still a consequent fraction in terms of generated waste and constitutive stocks, but insulation may represent a key fraction in future interventions. So even if weight is the common measurement in the waste sector, volume has to be considered in material stocks and flows analysis or some key fractions (present and future) may be missed.

Recoverability

The following figure synthetized the recoverability assessment issues for each envelope component considering the best improved wall solution (Fig. 4). Results are presented in a percentage score (the best one) depending on the degree of recovery studied (R^+ for reuse, R for recycling, C for composting, I for incineration potentials). The wall types indicated in the graph bars are the wall solutions presenting the best recovery potential (depending on the degree considered). Both units are represented: in grey the results considering weight and in dotted line the results considering volume.

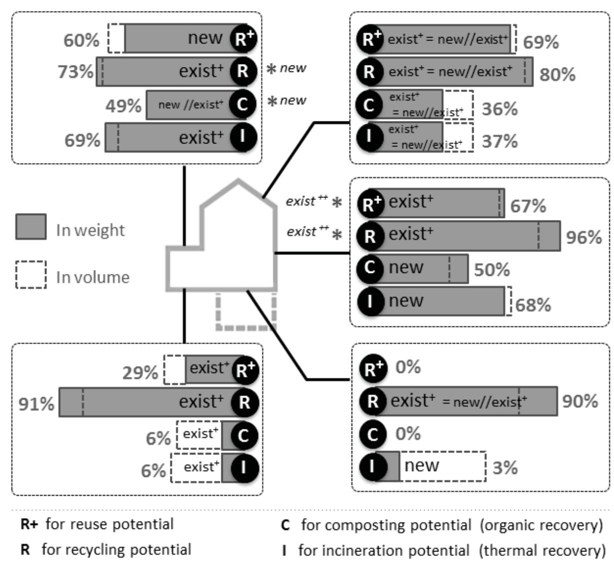

*Figure 4: Recoverability per component and valorisation degree in weight and volume (best scores presented): **exist⁺** or **exist⁺⁺** for existing wall type preserved and improved; **new//exist⁺** for existing wall type demolished and similarly rebuilt as exist⁺; **new** for new wall type*

The first observation is that there is no implemented solution that is globally the best for all kinds of external wall. The results depend on the components and the valorisation degree treated. However, the preserved and upgraded solution named *exist⁺* appears to be the most effective answer in most cases (13 on 18) followed by the rebuilt as identical wall *new//exist+* (6 on 18) and then the *new* wall types (4 on 18). Results are quite clear regarding the slab on grade and the sloped roof envelope components. They are more various for the façade, the flat roof and the slab above cellar. Comparing with the weight results, the outcomes in volume present more or less potential depending on the degree of recoverability and the envelope component. Despite the differences between the two units, the best solutions for improvement in terms of recoverability are quite similar. However there are a few exceptions (marked with and asterisk*). Amongst envelope components, it seems that the façade and roofs wall types have a bigger recovery potential than the slabs (above cellar and floor tile) except for the recycling potential, which is quite important in that case.

As going into details for each envelope components will represent a heavy description, we will focus on the case of the façade to clearly understand the assessment made for every wall type. The different façade wall types are presented above in figure 2 (Fig. 2) and the recoverability evaluation is shown in figures 5 and 6 (Fig. 5 and Fig. 6).

Considering the **results in volume** (Fig. 5), the preserved and upgraded wall type *exist*$^{++}$ presents the best results in terms of reusability (R^{+}) and recyclability (R), which are the most important degrees of recoverability. Its reuse potential is mainly due to the possible reversibility of the assemblies used: dry mechanical assemblies for timber structure and cladding, lime mortar for the existing masonry (even if it needs a careful and considerable manual labour). Since the *new//exist*$^{+}$ wall uses cement mortar for masonry as well as a synthetic rendering on an insulating material (EPS) glued on masonry, the whole consists of irreversible connections; therefore, its reuse potential is null. Except for its substantial recycle potential; this wall type presents poor recoverability.

The results are globally interesting about the recyclability (R). In the case of *exist*$^{+}$, *exist*$^{++}$ and *new//exist*$^{+}$ the huge proportion of inert material that has a good recycling rate mostly influences these outcomes. There is an organic recovery potential (C) only for wall solutions that are composed with vegetal-based materials such as wood and cellulose (only *new* and *exist*$^{++}$ walls are concerned). The thermal recovery potential (I) mainly concerns timber elements and insulating materials. This explains the huge differences between weight and volume for the masonry wall types (*exist*$^{+}$, *exist*$^{++}$ and *new//exist*$^{+}$): as the proportion of insulation in weight is negligible comparing with its proportion in volume, the outcomes are quite more attractive in that last case. Except for incineration (concerning all wall types) and organic recovery for *exist*$^{++}$, the overall **results in weight** (Fig. 6) offers a gain of potential comparing with the volume assessment. Nevertheless, for both units, the results for reusability and recyclability are the best concerning the preserved and upgraded wall types (*exist*$^{+}$, *exist*$^{++}$). Because of its composition (mainly wood and cellulose), the most organic and thermal recoveries are due to the *new* wall type. Still, in terms of priorities, reusability and recyclability are more important than composting or incineration potential.

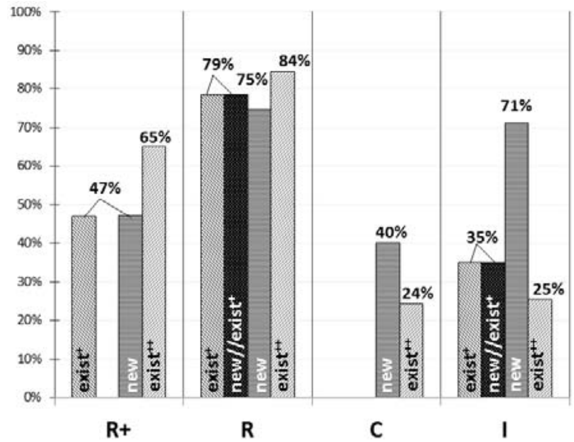

Figure 5: Recoverability in volume for the façade's wall types

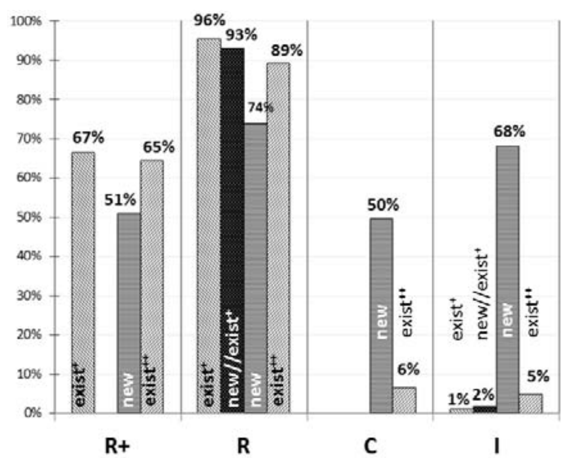

*Figure 6: Recoverability in weight for the façade's wall: : **exist**$^{+}$ or **exist**$^{++}$ for existing wall type preserved and improved; **new//exist**$^{+}$ for existing wall type demolished and similarly rebuilt as exist*$^{+}$*; **new** for new wall type;* R^{+} *(reuse), R (recycling), C (composting), I (incineration).*

CONCLUSION AND OUTLOOKS

In light of the current needs in terms of renovation mostly aimed towards energy performances of building, the present survey intends to offer a new point of view: a perspective based on matter and including the potential of resources the materials used in the building could represent. The second goal is to partially respond to the lack of data regarding the material flows and material deposit produced by energy retrofit operations. As a matter of fact, the data collection actually represents a substantial stage to achieve a more closed loop system and an efficient resource use.

The material balances conducted in this study have shown the importance of considering both weight and volume in stocks and flows analysis. It has also pointed out the significant proportion in volume of insulation materials in the new stock, after renovation. This means that, even if it is not a significant fraction in weight (2%), it represents a key fraction that we will have to handle in the medium or long term (depending on the renewal rate of the building sector).

Furthermore, the material balance conducted on typical retrofitted building may also generate ratio data that could rise, at a larger scale, to a prospective approach for a more integrated resource management. As this survey has only analyzed one case study, we cannot pretend to develop a reliable tool at this stage. Nevertheless, we believe that the methodology used to conduct this study represents a first but essential step to collect data on material deposit contained in building and cities. To further this research and extend it across the Brussels Capital Region, the developed methodology will be applied on other types of buildings through a new study project (funded by the European Fund for Regional Economic Development) that began last November. In a longer-term vision, this approach could allow the anticipation of potential flows generated by energy retrofit policies. It may therefore represent great opportunities to reach an efficient and responsible resource and waste management.

Concerning the recoverability it has been developed to inform designers about the impact of their construction choices in terms of future valorization potential depending on the constitutive materials and their implementation in wall types. Still it is important to keep in mind that prevention is the preliminary step to any other valorization. In this sense, maintain and improve constructed elements (compared to a demolition and reconstruction) provides resources and waste economies and brings to an environmental benefit. The qualitative assessment proposed by this research should not be a substitute for any environmental impact analysis but should be seen as complementary and additional. Used wisely, it would steer the constructive choices to optimize the current and future valorization of the material deposits contained in the building stock.

Finally, it is important to note that this assessment is a theoretical approach. It does not guarantee the future valorization of the constructed elements. This valorization will depend on various other factors: economic value, existent recovery streams, practices, etc. Still, the recoverability evaluation must be seen as a tool to help in the determination of the most appropriate solution in terms of recovery.

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