

URMIBALI project: How can digital documentation technologies be a support for urban mining and reuse of building materials? A new method for data acquisition on traditional residential buildings in Liège

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Abstract. The URMIBALI research project aims to develop, within an Urban Mining (UM) framework, a digital method for rapidly acquiring detailed data to inventory and quantify the existing materials deposits in old historic and traditional buildings in the city of Liège. The method's development follows a bottom-up and interdisciplinary approach, leveraging both six representative study cases, digital documentation technologies commonly used in heritage preservation, and existing historical and archaeological knowledge, including construction techniques and materials. This contribution outlines the various research steps, including a typological analysis of Liège's building stock built before 1919, a theoretical and quantitative inventory of material deposits in six representative study cases, a theoretical accounting of demolition waste flows generated by energy renovation operations, and the development of a digital method for rapid data acquisition. Additionally, it presents and discusses the results of the theoretical inventory of material deposits.

1. Introduction

1.1. Context and background

Wallonia, like many other European regions, is characterized by a diverse existing residential built environment, both urban and rural^[1]. This building stock is primarily comprised of single-family houses, along with a significant number of traditional old buildings as defined by Webb^[2]. Considered as energy intensive, it requires energy renovation by 2050 to meet European objectives regarding building energy efficiency as well as a rising focus on circular economic principles and sustainable resource and waste management^[3]. Energy renovations will accelerate, resulting in a significant rise in demolition waste.

While demolition waste account for 39% of all waste in Wallonia and have considerable environmental impacts, they are also considered, within an Urban Mining (UM) framework^[4] as valuable material resources. They can be directly reused in construction or repurposed as raw materials in production cycles^[5]. UM is a concept that highlights the availability of valuable material resources within the built environment and their potential for recovery through reuse and recycling. It distinguishes between existing material stocks or deposits and the flows generated by successive renovation



operations^[6]. In the construction sector, UM studies primarily center on residential buildings, using primarily top-down methodologies based on statistical data analysis^[7] and focusing on a single material such as metals, aggregates, sand, or concrete^[8]. However, despite their prevalence in old traditional and historic buildings, wood, stone, bricks, and tiles have not received thorough examination, although some research has investigated spatiotemporal frameworks for mapping structural bricks^[9] and the potential for reusing old bricks^[10]. Moreover, few studies have analyzed the entire deposit present in the old traditional building stock and/or the influence of energy renovation on waste flows, especially due to a lack of data and methods^[11].

Wallonia lacks detailed data with a high level of granularity regarding its residential building stock, the existing material deposit, and the demolition waste flows. Collecting such data can only be achieved through a bottom-up approach involving in-depth study of representative study cases of various building types and statistical analysis of renovation operations. Due to the diversity of the Walloon building stock, these studies are time-consuming, resource-intensive, and expensive. It is therefore urgent and essential to focus on developing an on-site, rapid, and reliable method of acquiring detailed data on existing buildings.

1.2. Scope and goals of the URMIBALI research project

In this context, the project URMIBALI aims to acquire knowledge about the material deposits in traditional old buildings in Liège and the waste flows generated by their energy renovations. The study focuses on residential buildings built before 1919, whether protected or not. These buildings account for 30% of the Walloon building stock and 53% of the Liège stock. They are well-documented^[12] and feature a diverse range of construction types, primarily using a limited selection of materials.

The first research objective is the development of a digital method for rapidly acquiring detailed data to inventory and quantify the existing material deposit, based on both six representative case studies, on digital documentation technologies commonly used in the field of heritage preservation^[13,14] and on existing historical and archaeological knowledge about traditional old buildings, including their construction techniques and materials^[15,16]. A second goal is to create a theoretical framework, based on various demolition scenarios, to anticipate the various waste flows generated during renovations.

2. Description of the methodological steps

The five methodological steps, presented below, follow a bottom-up and interdisciplinary approach.

2.1. Typological analysis and identification of main building archetypes

Based on a historical analysis of the geographical, economic, and political contexts that have shaped the development of Liège, a typological study was conducted to define building archetypes in terms of use, dimensions, spatial organization, and construction techniques. The analysis focused on two key periods: the first spanning from the late 17th century to the 19th century, and the second from the late 19th century to the early 20th century. Despite the overlapping and progressive modifications of the construction techniques, two main archetypes were identified: (1) the urban house which emerged from the medieval city intramuros parceling, characterized by a dense and narrow plot and influenced by the Mosan style, and (2) the bourgeois terraced house, built on more spacious plots along wider streets, reflecting French architectural influences.

2.2. Theoretical quantitative inventories of material deposits in the six study cases

The theoretical quantitative inventories of material deposits were developed thanks to the analysis of six study cases (*Figure 1*), selected for their representativeness in both construction techniques (use of wooden frames, thick brick masonry, and local stones) and building stock. According to Statbel, buildings constructed before 1919 account for 53% of the building stock in Liège. The goal is to better identify the nature, dimension and quantity of materials used in traditional old buildings and how they were implemented and assembled. These inventories will serve as the foundation for developing and validating the digital data acquisition method. To gather data on materials, available iconographic

documentation provided by building owners was used alongside a photographic survey and, in some cases, digital technologies such as photogrammetry and 3D scanning. The analysis primarily focused on envelope components, internal partition walls, and floors. However, it did not include building services, external and internal joinery, or interior finishes except for lime or plaster coatings.



Figure 1. The study cases chosen for their representativeness in terms of building techniques and materials

2.2.1. *Study cases analysis and decomposition.* To provide a systematic analysis approach, this step followed the decomposition method of the research project FEDER BBSM^[17]. Each study case was decomposed into components (roof, façade, and floor) and layers (external, internal and structural). The façade component, particularly solid brick masonry, was further analysed by floor level, as the wall thickness varies depending on the building's height and number of floors. A surface measurement was then conducted along with specific architectural elements. Finally, for each component, a quantification of the various materials layers was made considering the thickness of the three layers, the percentage of each material in layers and the material density (Figure 2). In addition, for Case 05, an extrapolation of the inventory results to the city level is currently in development, based on the cadastral map and register data from the General Administration for Patrimonial Documentation (AGDP).

Component or wall	Complete name	Layer	Type of layer	Number of materials	Type of material	Surface area (m ²)	Thickness (m)	Percentage in layer	Density (kg/m ³)	Total weight (kg)	Total weight (% of the wall weight)	Total volume (m ³)	Total volume (% of the wall volume)
Front façade													
Fa AV ss	Front façade basement	Li	Internal finishing	1	/								
				2	Lime coating	17,76	0,005	100%	1500	133,19	0,87	0,09	1,03
		Ls	Structure	3	Solid brick	17,76	0,480	90%	1800	13809,55	90,22	7,67	89,07
				3'	Lime mortar	17,76	0,480	10%	1600	1363,91	8,91	0,85	9,90
				4	/								
Le	External finishing	5	/										
Total - Fa AV ss							0,485			15306,65		8,61	
Fa Av rz	Front façade Ground Floor	Li	Internal finishing	1	/								
				2	Lime stucco	7,25	0,005	100%	1500	54,35	1,15	0,04	1,36
		Ls	Structure	3	Solid brick	7,25	0,360	90%	1800	4226,33	89,54	2,35	88,28
				3'	Lime mortar	7,25	0,360	10%	1600	417,42	8,84	0,26	9,81
				4	Cement coating	7,25	0,002	100%	1500	21,74	0,46	0,01	0,54
Le	External finishing	5	/										
Total - Fa Av rz							0,365			4719,84		2,66	

Figure 2. Decomposition of the front façade, by floor level – Study case 05

2.2.2. *Main materials descriptive sheets.* The most encountered materials in the study cases were then documented in descriptive sheets. These sheets detail the type and nature of each material, its dimensions, color, and texture, its state of conservation, its location within the study case, and its assembly method. Additionally, information on technical specifications, conventional end-of-life treatments, and key considerations for material reuse are also provided.

2.3. Theoretical accounting of the waste flows generated by rehabilitation operations

The third step, which is under development, aims to quantify and anticipate the waste flows generated by building's energy renovation, considered as potential resources for reuse. For each study case, three renovation scenarios were proposed, varying the percentage of demolition for each envelope walls and elements, and relying on both the literature^[18] and current Belgian renovation practices. They integrate

biobased insulation produced in Wallonia and comply with the Walloon EPB requirements in terms of U-value. For instance, the scenarios for Case Study 5 are illustrated in **Table 1**. The main waste flows generated by the renovation scenarios will then be analyzed in relation to available recovery systems (collect, reuse and recycling) near the city of Liège.

Table 1. Description of the rehabilitation works proposed in the three scenarios - Study case 05.

Walls	Scenario 01	Scenario 02	Scenario 03
Front Façade	No works	No Works	On the clearance height: removal of internal finishing and internal insulation with new finishes
Rear Façade	Removal of external finishes External insulation and new finishes	Removal of external finishes Window bay enlargement (30%) External insulation and new finishes	Complete demolition of the rear façade and new façade with wood frame and finishes
Pitched Roof	Removal of the roof covering (reused) Removal of the wooden lathing Insulation between rafters, with vapor barrier and new lather, rain-barrier membrane and internal finishes	Removal of the roof covering and wooden lathing. Removal of the wooden structure (30%) Insulation between rafters with vapor-barrier and new covering, lathing, rain-barrier membrane, and internal finishes	Removal of the roof covering and wooden lathing. Removal of the wooden structure (50%) External insulation between wooden frame and new covering, lathing, rain-barrier membrane, and internal finishes
Windows	Replacement of existing frames with high-performance double glazed wood frames	Replacement of existing frames with high-performance double glazed wood frames	Replacement of existing frames with high-performance double glazed wood frames
Slab (on cellar)	No works	No works	Removal of floor finishes and leveling mortar and rigid insulation with new dry screed board

2.4. Development of the digital method for rapid data acquisition

Based on theoretical inventories, the fourth step, also under development, aims to establish a digital method for acquiring qualitative and quantitative data on material deposits in traditional old buildings. This approach leverages both digital tools and artificial intelligence to enhance data collection, processing and analysis. A literature review was first conducted to identify digital technologies used in built heritage studies^[19], engineering sciences^[20], and remote sensing^[21] to provide data on wall morphology, general condition, state of conservation, and the nature of material components. Additionally, it examined semi-automatic data processing and machine learning approaches relevant to the research project. On this basis, a first data acquisition and processing protocol was proposed based on the archetype of the terraced bourgeois house. One of the main issues will be the integration of data processed by artificial intelligence (object detection, segmentation and image classification) within a georeferenced three-dimensional data system.

2.5. Cross-checking and balancing of data collected and processed

The final step involves cross-referencing data obtained through digital methods with theoretical inventories to create a quantitative materials inventory that closely reflects the actual built environment. On this basis, a balancing phase will refine and validate the numerical data acquisition method while assessing its accuracy.

3. Results

The results presented below focus mainly on the theoretical inventories of materials deposits and waste flows generated by renovation operation (for case 05). As presented in **Figure 3**, inventories enable a detailed assessment of materials, in mass and volume, by both wall and material type, while also allowing for overall building-scale evaluations. The inventories exhibit some uncertainties due to the lack of comprehensive iconographic documentation and precise data on certain original wall compositions and/or modifications, as well as the omission of certain components and materials. However, despite these limitations, they have revealed the predominance of solid brick masonry, which

accounts for more than 45% of the total mass and volume, particularly in the two case studies constructed during the 19th century (Figure 4). For the study cases built before the 19th century, they also highlighted a predominance of natural stone used in masonry or as a decorative element.

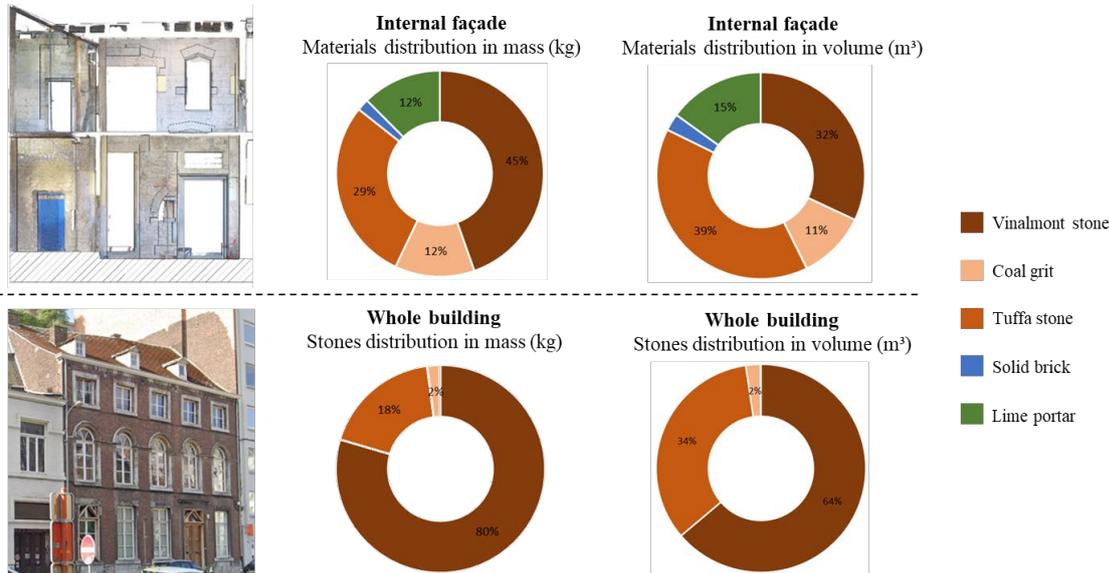


Figure 3. Study case 01 – Materials deposit of the internal façade and natural stones deposit of whole building.

These stones are primarily locally sourced materials, such as Vinalmont limestone, tufa, and coal grit. Solid brick and natural stone are found in front and rear facades, adjoining walls, as well as interior load-bearing walls and partitions. Lime mortar also represents a substantial portion of the material deposit, making up approximately 10% of the total mass and volume, as it is used in the construction of solid brick and stones masonry.



Figure 4. Materials deposits in mass and volume analysed in four study cases

The inventories also indicate that wood, whether used for structural elements or interior finishings, represents a small portion of the material deposit in both mass and volume. However, in the oldest case study, it represents about 15% of the deposit by mass and 30% by volume. Finally, they highlighted how a building's function influences material use. While the first three cases were residential, the last, originally a military structure for horses, required reinforced load-bearing elements and vaulted floors, resulting in a higher presence of cast iron, steel, and lime filler mortar.

In addition to the existing material deposits, the first estimation of waste flows generated by the three renovation scenarios for the study case 05 “Maison bourgeoise” are presented below, in **Figure 5**.

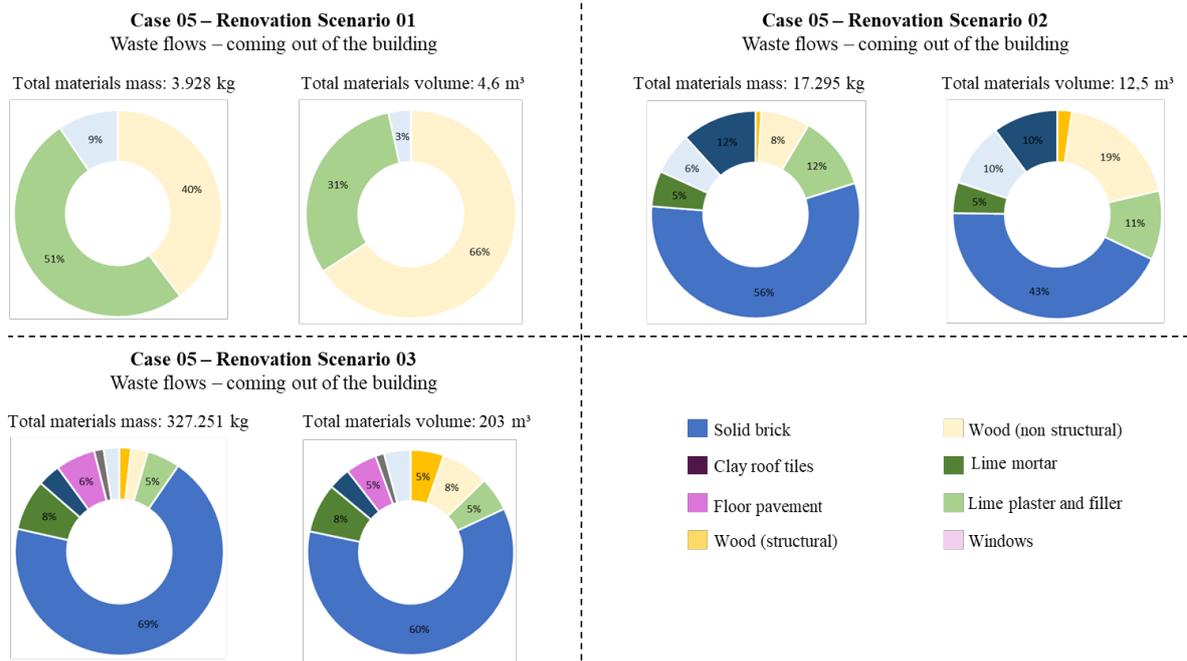


Figure 5. Waste flows generated by renovation scenarios – study case 05

4. Conclusion

Aligned the Walloon objectives for building’s energy efficiency and circular construction, the URMIBALI research project aims to identify and quantify building materials deposits in traditional old buildings in the city of Liège. It also seeks to anticipate waste flows resulting from the energy renovation of these buildings. The primary challenge lies in developing a digital method for the rapid acquisition of detailed data on the existing materials stock, including their type, dimensions, quantity, and state of conservation, based on a series of methodological steps presented in this contribution. The project's innovation lies in generating previously unavailable data on material deposits in traditional old buildings, adopting a multi-material focus, and ensuring the method's potential transferability and applicability to other built environments and cities. Both the developed method and the acquired data play a crucial role in advancing the circular economy and improving the management and reuse of construction materials. Additionally, they provide significant contributions to geographic information systems, heritage documentation, and building archaeology.

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