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Spatio-Temporal Analysis of Resources and Waste Quantities from Buildings (as Urban Mining Potential) Generated by the European Metropolis of Lille: A Methodology Coupling Data from Construction and Demolition Permits with Geographic Information Systems

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Abstract: The aim of this article was to conduct a spatial and territorial analysis of the urban mining potential of the European Metropolis of Lille (MEL), which had 1,174,273 inhabitants in 2018. This involved quantifying construction and demolition waste (CDW) deposits and analyzing their spatial distribution. The chosen quantification approach utilized building and demolition permits as input data, along with waste diagnostics for Construction and Building Materials Products (CBMPs) obtained from stakeholders in the building sector. Waste quantities were estimated using the production rate calculation method (GRC). Specifically, the calculation based on surface area combined with GIS geographic information systems. CDW quantities were categorized by demolition rehabilitation and construction; by type (hazardous non-hazardous inert); and by urban fabric. For the MEL area, the findings revealed that building sites covered the largest surface area, with over 8 million m² being constructed between 2013 and 2022. The construction activity, including renovation, is expected to constitute approximately 20% of the MEL's building stock from 2013 to 2022. During the same period, 5.51% of the MEL's building stock was demolished. This corresponds to nearly 6 million tons of CDW being generated during this period, averaging 661318 tons per year. Demolition sites contributed 73% of the total CDW production, compared to 22% for new construction and 4% for renovation sites. Inert waste continued to dominate the composition of waste, accounting for 90% of the total with 9% for non-hazardous waste and 1% for hazardous waste. Semi-detached and grouped houses business fabrics and townhouses or collective fabrics were identified as the primary type of waste-producing urban fabrics. Furthermore, our GIS-based methodology enabled the analysis of CDW quantity distribution by municipality, providing essential data for understanding the urban mining potential and the disparity between construction material requirements for new buildings and resources derived from building demolition. This approach facilitates the assessment of (1) a geographical area's reliance on construction materials, and (2) the significance of reusing and recycling products equipment materials and waste (PEMW) in new construction to achieve circular economy objectives and to comply with the Extended Producer Responsibility (EPR) channel initiated in France in 2023. Over the period from 2013 to 2022, annual construction material requirements remained significantly higher than resources from building demolition and rehabilitation, ranging between 29% and 35%. Additionally, the analysis indicated a potential 41% rate of substitution of new construction materials with secondary primary materials in the MEL, varying by municipality and typology, with higher rates in rural communities and lower rates in urban communities.

Keywords: demolition waste; construction waste; C&D permits; GIS; spatial analysis; MEL

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Citation: Simba, C.M.; Lemelin, E. Spatio-Temporal Analysis of Resources and Waste Quantities from Buildings (as Urban Mining Potential) Generated by the European Metropolis of Lille: A Methodology Coupling Data from Construction and Demolition Permits with Geographic Information Systems. *Resources* **2024**, *13*, 76. https://doi.org/10.3390/resources13060076

Academic Editor: Benjamin McLellan

Received: 2 April 2024
Revised: 26 May 2024
Accepted: 28 May 2024
Published: 3 June 2024

1. Introduction

Rapid urbanization or the expansion of urban areas is leading to a significant increase in building stock, accompanied by the extensive demolition of buildings. These construction and demolition (C&D) activities generate a substantial amount of waste. In Europe, the construction sector is the largest producer of waste, both by volume or by weight [1]. In France alone, approximately 46 million tons are generated per year [2]. Construction and demolition waste has adverse environmental effects, as construction activities consume natural resources materials water and energy [3]. In the broader context of emerging environmental protection policies that are driven by a collective awareness of the impending depletion of primary resources, preserving raw materials has become a crucial issue.

To alleviate the pressure on raw materials policies, promoting circular economy approaches and reuse are increasingly being implemented. This trend is evident in Europe, with initiatives like the Green Deal, as well as in France, with policies such as the energy transition for green growth (LTECV 2015) and the government's circular economy roadmap (FREC 2018). These policies align with waste recovery through circular economy principles and the reuse of Construction and Building Materials Products (CBMP). Recycling and reuse not only yield economic benefits, but also promote environmental protection by reducing or mitigating the demand for primary resources [4,5]. According to reference [5], construction and demolition waste (CDW) possess a significant recycling and reuse potential, estimating that around 80% of construction waste can be repurposed.

In France, recycling and recovery targets have been revised by ADEME as part of the Prefiguration Study of the Extended Producer Responsibility (EPR) channel of Construction Products and Materials Products (CPMBCBMP) in the building sector [2]. Various trajectories and alternatives have been explored depending on the type of waste (inert waste and hazardous waste). The overall recovery target for inert waste is proposed to reach 90% within six years compared to the current rate of 77%. Hazardous waste is expected to be recovered at a rate of 50% compared to the current 26%.

For these policies and objectives to be effective, they must be grounded in comprehensive knowledge of available resources or deposits. Quantifying CDW generation is seen as a crucial step for the implementation of successful waste management [6]. Therefore, estimating the amount of waste a geographical territory can generate is vital for organizing and planning the expansion of reuse and recycling within a circular economy framework.

1.1. Literature Review

There are several methods for quantifying waste (refer to Table S1 in the Supplementary Material). To help inform the choice of future research, ref. [3], in an article entitled "Estimation Methods of construction and demolition waste generation: a review", conducted an extensive literature review on existing waste quantification methods. Primarily, the article illustrates how one method may be favored over another, considering the types of data and the contexts involved. It is important to note that this literature review does not aim to conduct a comparative analysis of the various existing methods to highlight their deficiencies. Rather, our objective is to present and describe the existing methods, outlining their peculiarities. Subsequently, based on our data, we select the most appropriate methodological approach. The different methods described below are summarized in Table S1 (see the Supplementary Material Section). A distinction is made between basic methods and so-called global methods (Table S1).

Table S1 shows the scope of each method and how CDW is assessed. Each of these methods is presented and described below.

Site visit (SV) method. This method can be used to measure the waste generated by all waste-producing activities. However, it is difficult to implement because it is labor-intensive, time-consuming, and expensive. It is also effective for collecting real data at the project level but not at regional level. In fact, the approach consists of carrying out surveys on construction or demolition sites to collect actual information. Two approaches, direct or indirect, are used to collect data on the production of C&D waste: (1) *Direct measurement* involves weighing the waste produced or measuring its volume on site, while (2) *Indirect measurement* is used to make estimates or deduce the volume of waste from readings (of lorry loads at landfill sites). On-site interviews with stakeholders in the sector are suggested to adjust the calculated production rate [7].

Production rate calculation method (GRC): This is the most widely used method for quantifying CDW at both the project and regional levels. It can be applied to construction, renovation, and demolition projects at various scales. The methodology aims to obtain the waste production rate for a specific unit of activity (e.g., kg/m^2 or m^3/m^2). It utilizes the following three main parameters: the per capita multiplier, financial value extrapolation, and area-based calculation [8,9].

Geographic Information System (GIS): This method is typically combined with area-based calculations to estimate the quantity of waste generated in each area. For example, ref. [10] developed a GIS-based approach to estimate demolition waste generation and the trends of economic values in Shenzhen. GIS software is used for data processing, including the importation of data such as demolition waste generation index, building demolition time, building type, and recycling potential. Similarly, ref. [11] suggested the possibility to obtain a spatial distribution of solid waste in a specific geographical area by considering its generation, composition, and variation throughout the year using GIS. Additionally, ref. [12] conducted a spatial analysis of urban material stock using clustering algorithms.

Building information modelling (BIM): This approach relies on tools that are capable of constructing a digital (3D) model of the building, enabling the extraction of information on volumes and materials. It is suitable for estimating CDW at the project (building) scale and can be combined with other methods such as the surface area calculation method [13,14].

Variable modelling method (VM). To model waste production, this method is based on the interrelationships between systematic variables. When estimating CDW production, variables are considered collectively, and their interrelationships are detected. Predicting CDW quantities through modelling helps to provide more systematic information for decision-making [15].

Accumulation method of the classification system (CSA): This method is developed for materials classified as C&D waste. It accounts for the different recycling benefits and disposal choices, based on the waste generation rate per unit and the total number of units [3]. Developed on the basis of the GRC method, it involves the determination of the quantities of all elements and the calculation of the total amount of waste by accumulating these elements. Computer software or databases are often used to facilitate the application of CSA (Solis Guzman et al., 2009) [16].

Material flow analysis (MFA) approach: This method examines the inputs and outputs of construction materials in use over the course of a year to determine the overall flows of construction activity. By combining MFA with the weight per construction area method, it becomes possible to estimate the amount of CDW generated in a region [3,16,17].

However, other methods not listed by ref. [3] exist. These include the Lifetime Analysis (LA) method, which analyzes the potential lifetime of buildings to quantify demolition waste. The LA method operates on the principle of the mass balance of materials, assuming that the quantity of demolition waste equals the mass of the structure built. By knowing the life expectancy of building materials, the quantity of materials available in a given area can be estimated [18,19]. Additionally, ref. [20] estimated the production of construction waste by defining a fixed percentage of waste from the materials purchased, assuming this percentage to be 10%. Consequently, the total quantity of construction waste is estimated to be equal to 10% of the materials purchased.

In light of the above, the main objective of this article is to quantify and analyze the potential for waste production in the geographical area of the European metropolis of Lille. This territory, covering 672 km^2 and comprising 95 municipalities, has a population of 1,174,273 [21]. This methodology can be replicated for all European regions, as long as the necessary data types are available (e.g., GIS of urban fabrics, waste diagnosis, available data on building and demolition permits). Quantification considers both demolition and construction waste. The proposed approach combines the GRC method for estimating waste deposits with GIS for spatial analysis. The methodology is applicable at both project (individual) and regional levels.

1.2. Quantifying Waste: The National Context

Quantifying construction waste remains a major challenge, particularly in France. Official data from government bodies estimate annual waste production at around 46 million tons. This quantity is estimated by cross-referencing different sources of data at the national and regional level [2]. The breakdown of waste by type and category is shown in Table 1 below.

Table 1. Annual estimate of CPMB waste in France. Source: [2] ADEME et al., 2021.

Categories	**Materials (Waste)**	**Quantities (kt)**
Inert waste (IW)	Concrete	17,000
	Terracotta	3000 to 4000
	Inert mixed waste	1000 to 11,000
	Flat glass	200
	Subtotal (IW)	≈30,000
Non-hazardous non-inert waste (NHNIW)	Metal	>3000
	Wood	2230
	Plaster	600
	Mineral wool	250
	Soft PVC	50
	Rigide PVC	60
	PSE	19.8
	Hard plastics (PP/PE)	28
	Polyurethane	10 to 13
	Carpets	30
	Bitumen membrane	80
	Mixed NND/NIHW not identified by the sectors	≈3400 kt
	Subtotal NHNIW	≈9700 kt
Hazardous waste (HW)	Asbestos	570
	DEEE	200
	Specific diffuse waste	100
	Treated wood	<13
	Subtotal HW	Between 900 and 1700

In detail, ref [2] shows that at the national level, 51% of waste is generated by demolition, 36% by renovation and 13% by new construction. The methods used to quantify the amount of waste generated are not detailed. Generally, the estimates made are the result of extrapolating data or ratios by type of construction site provided by professional bodies [22,23]. Quantifying waste from the construction sector is not an easy task. The complexity arises from various factors, including the heterogeneity of sources (such as demolition, rehabilitation, and construction); the involvement of different stakeholders (such as public/private real estate and waste management companies); and diverse collection methods (in situ data, waste diagnostics, and diagnostics of CBMP). Additionally, the diversity in organizational structures and the scale of construction sites further complicates the matter [23]. Consequently, the level of detail and accuracy of the information varies significantly, depending on the sources and collection assumptions utilized. In addition to extrapolating and compiling data supplied by professional bodies, the Agency for the Environment and Energy Management (ADEME) and the Regional Economic Unit for Construction (CERC) use the tonnage of materials placed on the market by major type to quantify the sources. However, these studies do not provide sufficient detail on the source data used (number of buildings or sites, their type, surface areas demolished, etc.). The study of waste and materials carried out by the CERC and the studies of the regional plans used data from 3000 sites receiving waste, without any further details being given. Ref. [2] is being carried out on a national scale. In the light of the above, we propose a quantification of CDW on the geographical area of the MEL. The quantification method is based on the use of waste diagnostics from different urban fabrics, combined with data from demolition and construction sites recorded (permits) in this geographical area between 2013 and 2022, that are classified by urban fabric and qualified using GIS attributes.

2. Materials and Methods

In the research program of the RECONVERT industrial chair, estimation of resources and waste from the demolition, construction, and rehabilitation of buildings generated in the MEL is one objective. The specificity of the approach is that it goes beyond the typology of the sites (demolition, rehabilitation, and construction) by also taking into account the type of urban fabric. This analysis of the quantification of waste according to the type of urban fabric is the first of its kind concerning the geographical area of the MEL. It will therefore provide information with a level of detail and precision on the scale of a geographical area. The proposed method is intended to be reproducible at the national and European level.

2.1. Data and Tools

Waste deposits will be quantified by combining data from several sources. We mainly used building and demolition permit databases, as well as waste diagnostics and diagnostic data from the Building Construction Products and Materials (CPMB) sector. These have been collected from professional deconstruction and construction bodies. The C&D permits are open data collected on the Sitadel site (https://www.data.gouv.fr/fr/datasets/base-des-permis-de-construire-et-autres-autorisations-durbanisme-sitadel/, accessed on 15 February 2024). In addition to the csv files, we also used GIS layers, including buildings, urban fabrics, and the administrative boundaries of the MEL. The C&D permit files and the data from the waste diagnostics will be combined with the GIS layers in order to carry out a spatial analysis of the waste potential of metropolitan areas. All of the geospatial processing required for the spatial analysis will be carried out using QGIS 10.3 software. Pre-processing is required in order to spatialize the C&D permit data. A common identifier between the GIS layers and the C&D permit files has been created. This makes it possible to match each C&D permit to the building and urban fabric to which it belongs. This correspondence is achieved by means of attribute and spatial joins. In this way, it will be possible to quantify, on a territory-by-territory basis, the number of C&D worksites, waste deposits, and their spatial distribution by type. Data used and their source were those of a previous and recently published article [24].

2.2. Description of the Methodological Approach

The approach chosen for estimating the quantity of waste is mainly based on the method of calculating the production rate (GRC). The choice is guided by the typology of our data, as well as the applicability of this approach on both the regional and project scale [3,10]. It is important to note that our focus will be on a regional scale (the MEL). However, utilizing GIS facilitates this transition by amalgamating site-level data with regional-level generation (MEL). The GRC method, coupled with GIS, encourages a multi-scale analysis. Additionally, the GRC method employs the following two indicators: the calculation of production rate per unit area and the multiplier per inhabitant [10,11].

The first approach will involve analyzing data collected from demolition and construction stakeholders (waste diagnostics and CBMP). The second approach will be utilized for a comparative analysis between our quantification results and the official data produced at national and European levels.

Calculation of the Production Rate (t/m^2)

To estimate or quantify waste production in the MEL and its territories, we have collected data from professional bodies in the construction sector and from local authorities. These were mainly waste diagnostics and PEMD. In total, we analyzed more than 15 waste audits and EHSMPs, in addition to summary data from the MEL's new urban renewal program (NPRU). The diagnostics represent a panel of around 251 buildings, compared with 79 sites for the NPRU data, giving a total of 330 sites across the MEL. In detail, demolition projects account for around 58% of the total, compared with 42% for rehabilitation and renovation projects. All the data (330 sites) were then classified according to urban fabric. It should be noted that the MEL has nine (9) urban fabrics. These data, collected in the form of a GIS layer, were produced with ADULM (described into a previous article [24]. We have subsequently classified the waste and PEMW diagnostic data and the NPRU data according to urban fabric. However, the C&D site data collected cover only 5 urban areas: 230 sites for pavilion fabric, 51 for collective fabric, 23 for fabric of semi-detached or grouped houses, and one for dense continuous urban fabric.

It should be pointed out that the absence of data for the farmhouse, terraced house, upper town, and amenity fabrics does not mean that there is no demolition in these fabrics in the MEL. As the information corresponding to these fabrics were not available in our sampling, these data were introduced empirically based on existing data: for "undefined fabric", the means of all urban fabric data had been used; "farm fabric" corresponded with the average of "activity fabric" and "fabric of semi-detached"; "townhouse fabric" and "upper town house fabric" corresponded with the average of "dense continuous urban fabric" with "fabric of semi-detached"; and "equipment fabric" associated with the "activity fabric". Then, the missing data for these urban fabrics have been extrapolated from the data of the other urban fabrics, in the aim of quantifying materials according to the available shapefile of urban fabric that qualify all buildings of the MEL. At the national level in particular, the estimates made rarely take account of urban fabrics. Moreover, the results produced are global (on a national or regional scale), so that studies with this level of detail are rare. To do this, several pieces of information from individual buildings or demolished sites were extracted. This includes the type of urban fabric, the quantity of waste by type (in tons), and the surface area demolished (m^2). The aim is to obtain a set of actual demolition data that concern all types of urban fabric and which can be used as training data to calculate an average weight per type of waste in tons per unit area (m^2). This is the ratio between the quantity of materials demolished by type and the gross floor area (Equation (1)).

$$\mathrm{IPD}(\mathrm{t/m^2}) = \mathrm{Q}(\mathrm{m}, \mathrm{u})/\mathrm{Sd}(\mathrm{shob}), \tag{1}$$

where

IPD: corresponds to the waste production index in tons/m^2. The values have been calculated for the waste or materials listed in our databases. Zero values mean that the quantities of waste have not been identified and do not appear in the diagnostics of the buildings concerned.

For all the materials and fabrics analyzed, the values for inert waste are the highest. They are mainly dominated by bricks and tiles as well as concrete and stone. This result is typical of the types and/or categories of waste most generated in the MEL.

In addition to the weight (t/m^2) for each waste material (Table S2), two other averages were calculated. These are the average weight of all waste in an urban fabric, which corresponds to the average unit weight per material (t/m^2) in a fabric. In other words, this value refers to the average of all waste combined for an urban fabric. The result of this calculation is presented in Table 2 below. It shows that two urban fabrics stand out, namely dense urban fabric, with an average of 2.07 tons of waste per m^2 demolished, and collective fabric, with 2.29 tons of waste per m^2 demolished. Apart from the suburban fabric, which records less than one (1) ton per m^2, all the other fabrics have more or less the same values (Table 2).

Table 2. Average weight of waste by urban fabric (t/m^2).

Urban Fabric	Average Weight (t/m^2)
Pavilion fabric	0.9054
Activity fabric	1.6541
Fabric of semi-detached or grouped houses	1.2148
Dense continuous urban fabric	2.0694
Collective fabric	2.2958
Upper town house fabric	1.6421
Equipment fabric	1.6541
Townhouse fabric	1.6421
Farm fabric	1.4345
Undefined fabric	1.6125

The second value calculated is the average of all fabrics combined for a waste item. This value was assigned by default to urban fabrics that had no training data. The average value assigned to these fabrics (without data) also includes the possible convergences in terms of type of construction materials that exist between certain urban fabrics. The reasoning implies that there is no fundamental difference in terms of construction materials between the "dense continuous urban fabric" and that of "high town houses", for example. The average values obtained for most of the fabrics (upper town house fabric; equipment fabric, townhouse fabric; and farm fabric) confirm this hypothesis (Table 2). The average values calculated from actual data from the various demolition sites are used as indicators for quantifying waste. Results are relying mainly on data from building and demolition permits granted in the MEL territories between 2013 and 2021. C&D permit files are urban planning authorizations and constitute public and accessible data (our compiled database and the methodology is presented in [24]. However, these building, demolition, or rehabilitation permits do not contain data on the quantities of materials or waste but only individual information on the buildings (surface area demolished or built, location, number of stories or height, year, type of building, address, postcode, etc.). The data from the C&D permits were processed and then classified by urban fabric (consistency between the parcel identifier and the GIS shapefile) and by type of worksite (demolition, rehabilitation, or construction) [24]. To calculate the quantities of waste, we base our calculations on the surface area of each building identified in the GIS as having been the subject of a C&D permit between 2013 and 2021. The total surface area demolished or to-be-built is information that appears on the C&D permit files. However, some files did not contain this information because it is not compulsory. For these permits, the total surface area of each building was therefore calculated after extracting the floor area from the ADULM GIS and the number of stories or height of the building from the national building database (BNDB). This approach to generating missing data has been used in several CDW quantification studies. The total quantity of materials from demolition sites is estimated, using the GRC method, by multiplying the total surface area demolished or rehabilitated (right-of-way × level) by the unit weight of the materials (t/m^2). In other words, the quantity of demolition waste can be calculated after defining the volume generated per unit area of the building and the mass of material per unit volume [25].

Furthermore, although construction requires the input of materials, it also generates waste [26,27]. It is therefore important to also consider the waste generated by new construction. To estimate the quantities of waste resulting from construction, we apply an average value corresponding to the mass of materials lost during construction. This has been estimated at around 50 kg/m^2 by [26,27]. Finally, by knowing the unit weight of materials (t/m^2; kg/m^2), it is possible to estimate the total stocks of materials in an area, and therefore the potential need for its renewal. The results make it possible to analyze certain aspects of the MEL's urban metabolism, by calculating incoming and outgoing material flows and the available stock.

In this study, a spatial analysis using GIS is proposed, with the aim of highlighting the urban mining potential of the areas that make up the MEL. This involves estimating building material requirements (calculated based on building permits) and available resources, derived from the demolition, rehabilitation, and construction of buildings. This analysis will be carried out for each MEL municipality (depending on the data available) and by year (from 2013 to 2022). Finally, the overall results (total quantity of waste) of our approach will be compared with the official data produced at the national and European level. Here, we will mainly use the per capita multiplier to compare our results with those of ADEME (national level) and EUROSTAT (European level). An index of waste production per inhabitant and per year will be calculated, allowing us to discuss any discrepancies between the various sources.

2.3. Using AI Chatbot ChatGPT 3.5 to Improve the Quality of English

To enhance the quality of English in our article, we employed the "improve the quality of English by keeping all references in square brackets and quantitative data included without paragraph numbering" request within the AI chatbot ChatGPT 3.5 (free) and simply cut and pasted the paragraph that seemed to us to be of low quality. We subsequently reviewed and edited the text where necessary, particularly in sections that appeared less polished or where the meaning was unclear. Estimation of the "modification rate" given by ChatGPT ranged from 10 to 50%; to estimate the rate of modification, ChatGPT 3.5 compares the original version with the revised version and analyzes the changes made, including grammatical corrections, style improvements, content additions, and any other substantial modifications. Then, ChatGPT 3.5 considers the proportion of text modified relative to the total length of the text to obtain an approximate estimation of the rate of modification using the command "Improve the quality of English".

3. Results

3.1. Analysis of the Spatial Distribution of C&D Worksites

One of the special features of our approach is that it is based on the use of building and demolition permits to quantify materials. In France, for each demolition permit, one or more buildings for which demolition generates waste could be considered. This waste can then be reused or recycled and considered as resources. Similarly, each building permit corresponds to one or more buildings for which construction requires materials (material requirements). An analysis of the dynamics of C&D permits granted has been carried out for all MEL municipalities over the period from 2013 to 2022. C&D permits are recorded monthly. The data are complete (i.e., over 12 months) for all years except 2022, which only includes data for 4 months [24]. Processing of the C&D databases has made it possible to classify them into three categories or types of worksites. Thus, over the entire period, 24,153 C&D permits were recorded in the MEL. In detail, this corresponds to 11,879 new-build sites, including preliminary building declarations, 7192 rehabilitation sites, and 5092 demolition sites (Figure 1). New-build sites account for 49% of the workforce, followed by refurbishments (30%) and demolitions (21%).

The building and demolition permit data do not have spatial references. Processing was carried out with the aim of preparing a single GIS layer containing all the attribute data required for spatial analysis. Building data, C&D permits, and urban fabric will be merged to form a single working layer. This layer constitutes a database to help quantify waste from C&D activities. The aim is to obtain a GIS classifying C&D permits by year, by type of building site, and by urban fabric in all the communes of the MEL between 2013 and 2022 (data available).

Initially, a classification of building site data by year enabled us to observe the year-on-year dynamics by type of building site (Figure 2). On average, around 1100 permits were granted for new construction each year, while around 700 permits were granted for renovation each year. As for demolition permits, from 2013 to 2022, their average annual number is around 500 (Figure 2). It can also be seen that for all years, the number of building permits, including renovations, remains higher than demolitions (Figure 2).

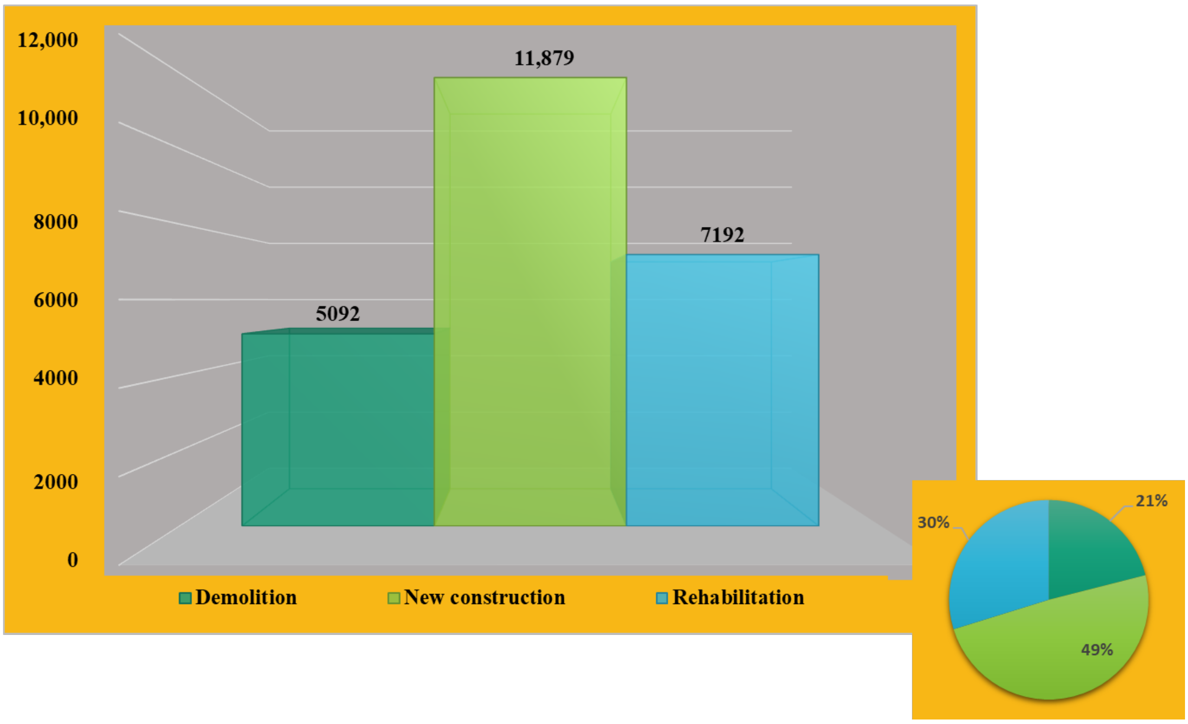


Figure 1. Classification of C&D licenses by type of worksite.

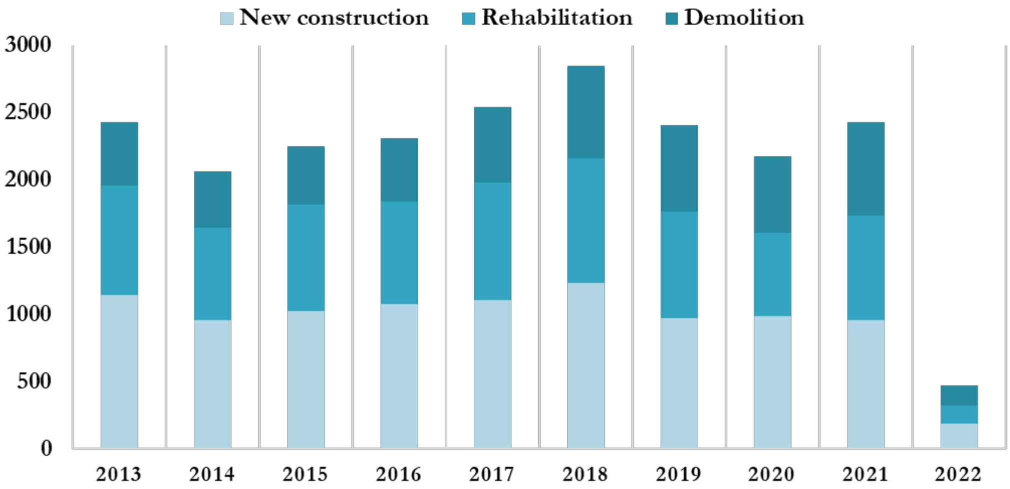


Figure 2. Year-on-year trends in C&D permits (number) by type of worksite in the MEL.

For all construction sites, the annual allocation trend remains relatively stable throughout the period, except for 2018, which saw a peak in all categories. On the other hand, in 2020, there is a slight drop in the various headcounts compared with 2017, 2018, 2019, and even 2021, which saw a recovery. This variation may be linked to the effect of COVID-19, which has slowed the construction sector. Also, the data for 2022 are incomplete because the permits collected cover only 4 months (January–April). The data from May to December 2022 had not yet been integrated into the Sitadel database when the methodology and data processing were set up. They are used here for illustrative purposes to observe trends [24].

All building sites were subsequently categorized based on the urban fabric to which they belonged (Table 3). This analysis was conducted using geospatial processing, integrating C&D permit files with the urban fabric layer. A parcel identifier was established beforehand, facilitating attribute joins to link each building to its corresponding urban fabric. For each building or C&D site, we extracted and computed the actual surface areas demolished and constructed (see Table 3). These data aid in the analysis of demolition and construction dynamics, offering insights into waste quantity potentials. Given that the chosen quantification approach relies on surface area, it is presumed that building sites and urban fabrics with larger demolished surfaces will harbor larger waste deposits. Table 3 displays the actual surface areas built, rehabilitated, and demolished between 2013 and 2022 for each building site type, categorized by urban fabric (Table 3).

Table 3. Breakdown of the different types of building sites and their surface areas according to urban fabric. Rehab: rehabilitations; NC: new constructions; Demol: demolitions. The percentages are calculated on the basis of the total surface area of buildings in the MEL (50,517,395 m^2).

Urban Fabric	**NC**	**NC %**	**NC Area (m^2)**	**Rehab**	**Rehab %**	**Rehab Area (m^2)**	**Demol**	**Demol %**	**Demol Area (m^2)**
Farm fabric	248	0.27	137,424	186	0.09	45,514	138	0.10	48,614.65
Pavilion fabric	1.123	1.63	824,588	544	0.219	110,471	323	0.30	148,933.59
Fabric of semi-detached or grouped houses	2.755	4.32	2,180,286	1594	0.575	290,710	1104	1.12	566,205.13
Townhouse fabric	1.939	3.18	1,605,927	874	0.322	162,669	981	0.67	340,607.52
Upper town house fabric	272	0.41	209,422	163	0.062	31,505	145	0.10	48,631.21
Collective fabric	438	0.90	453,716	163	0.055	27,980	148	0.24	121,819.30
Dense continuous urban fabric	852	1.05	531,501	814	0.3	151,683	299	0.35	176,423.08
Equipment fabric	1464	1.87	941,901	1264	0.508	256,649	730	0.83	418,504.84
Activity fabric	1613	2.19	1,107,497	1048	0.7	353,548	685	1.37	689,828.44
Undefined fabric	1175	1.33	669,416	542	0.512	258,485	539	0.45	225,944.69
TOTAL	11,879	17.15	8,661,678	7192	3.344	1,689,214	5092	5.51	2,785,512.45

For the Lille metropolitan area, the construction dynamic, including renewal, will account for around 20% of the MEL's building stock between 2013 and 2022. During the same period, 5.51% of the MEL's building stock was demolished. Building sites occupy the largest surface area, with more than 8 million m² built between 2013 and 2022. Although the number of renovation projects (7192) is higher than the number of demolitions (5092), the total surface area renovated remains significantly lower than the total surface area demolished (Table 3). Detailed data on the dynamics of building sites by urban fabric are presented in Table 3 [5]. These data illustrate the varying degrees of demolition, construction, or rehabilitation activity across different urban fabrics. Consequently, it offers insights into which urban fabrics exhibit higher or lower levels of such dynamics, providing an indication of the potential waste generation within the MEL [5]. The underlying assumption is that a correlation exists between the total surface area demolished within a particular urban fabric and the corresponding quantity of waste generated, according to Table 3. In this respect, Table 3 shows that the business, equipment, and semi-detached and grouped house fabrics are those that will potentially produce the most waste because they have a large demolished surface area.

In addition, the spatial analysis of C&D sites using GIS enabled them to be located by commune (Table S3 in the Supplementary Material Section). The typological distribution of C&D permits and their location thus contribute to the analysis of urbanization dynamics. This shows that the main urban centers, including Lille, Tourcoing, Villeneuve d'Ascq, Roubaix, Armentières, etc., are consuming much more space much more quickly and extensively than the rural municipalities, where the amount of land built, renovated, or demolished remains very low (Table S3). Above all, this spatial analysis enables us to put the key locations into perspective. Using them, we can estimate the degree of constructability (construction dynamics) and deconstructability (demolition dynamics) for each municipality. It also provides an initial understanding of the potential of urban mining by highlighting the areas with the highest levels of demolition and reconstruction per fabric. In this way, the data produced can be used as input for CDW quantification methods. It also helps to analyze the region's dependence (or self-sufficiency) on CBMP, as it can be used to measure the gap between the need for construction materials and the resources generated by deconstruction, as shown in [28,29]. These data constitute a knowledge base for the spatiotemporal and typological analysis of CDW in the MEL.

The data produced in the previous sections serve as a knowledge base for our approach to quantifying C&D waste. It should be remembered that the specificity of our approach is that it provides original data on waste production indicators according to urban fabric (average weight of waste per unit area (t/m^2)). These average weights are calculated based on actual data from C&D sites, classified by urban fabric, in the MEL. This approach to quantification by urban fabric is the first of its kind, particularly in France. Even internationally, very few studies offer this level of detail. In many studies, the distinction is often limited to residential and non-residential buildings [25,30,31], so that the quantification of waste according to urban fabric is hardly addressed.

The following section presents the results of the quantification of materials in the MEL. Firstly, the overall results by type of urban fabric, worksite, and material are presented. Next, the quantities of waste are analyzed, considering inter-annual dynamics and their spatial distribution. Finally, the urban mining potential is addressed by analyzing the gap or difference between construction material requirements and the resources generated by the demolition and construction of buildings.

3.2. Quantification of C&D Waste

3.2.1. Dynamics of C&D Sites by Type of Urban Fabric

Table 4 summarizes the estimated production of CDW from building demolition and construction activity in the Lille European Metropolis from 2013 to 2022. In total, almost 6 million tons of CDW were generated (Table 4). The proportion of demolition waste to total CDW generation is 73% over the period 2013–2022, or 4,369,159 tons. Construction activity was divided into two groups, namely new builds, which produced 22% of total waste generation, or 1,318,423 tons, and rehabilitations, which generated 4% of waste, or 264,159 tons (Table 4).

Table 4. Total quantity (tons) of CDW generated by type of construction site and by urban fabric in the MEL from 2013 to 2022.

Urban Fabric	Construction Waste	Rehabilitation Waste	Demolition Waste	C&D Waste
Farm fabric	19,713	6529	69,738	95,980
Pavilion fabric	74,662	10,003	134,851	219,515
Grouped houses fabric	264,860	35,315	1,141,063	1,441,238
Townhouse fabric	263,709	26,712	687,822	978,243
Upper town house fabric	34,389	5173	365,091	404,653
Collective fabric	104,163	6424	559,311	669,898
Dense continuous urban fabric	109,989	31,389	79,857	221,236
Equipment fabric	155,802	42,453	279,669	477,925
Activity fabric	183,194	58,481	692,260	933,935
Undefined fabric	107,942	41,680	359,626	509,248
Total	1,318,423	264,159	4,369,288	5,951,870

Table 4 and Figure 3 also provide an analysis of waste generation by urban fabric. This varies according to the type of worksite. For all types of construction sites, four urban fabrics stand out in terms of waste production. These are, respectively, the semi-detached or grouped house fabric, the terraced townhouse fabric, the business fabric, and the collective fabric. These urban fabrics produce the most waste in the MEL. They generated over 64% of total waste production, i.e., 3,811,387 tons. These urban fabrics correspond to the most demolished, but also the most built-up buildings in the MEL. In detail, it is the semi-detached or grouped housing fabric that is the most demolished (1,141,063 tons) and the most built (264,860 tons). The most extensive renovation work was carried out on commercial (58,481 tons) and industrial (42,453 tons) properties. On the other hand, for all types of construction sites, the farm fabric produced the lowest quantities of waste, at 1.61% of total production. This was followed by the residential sector with 3.69%, or 219,515 tons. The results of this analysis are summarized in the figure below.

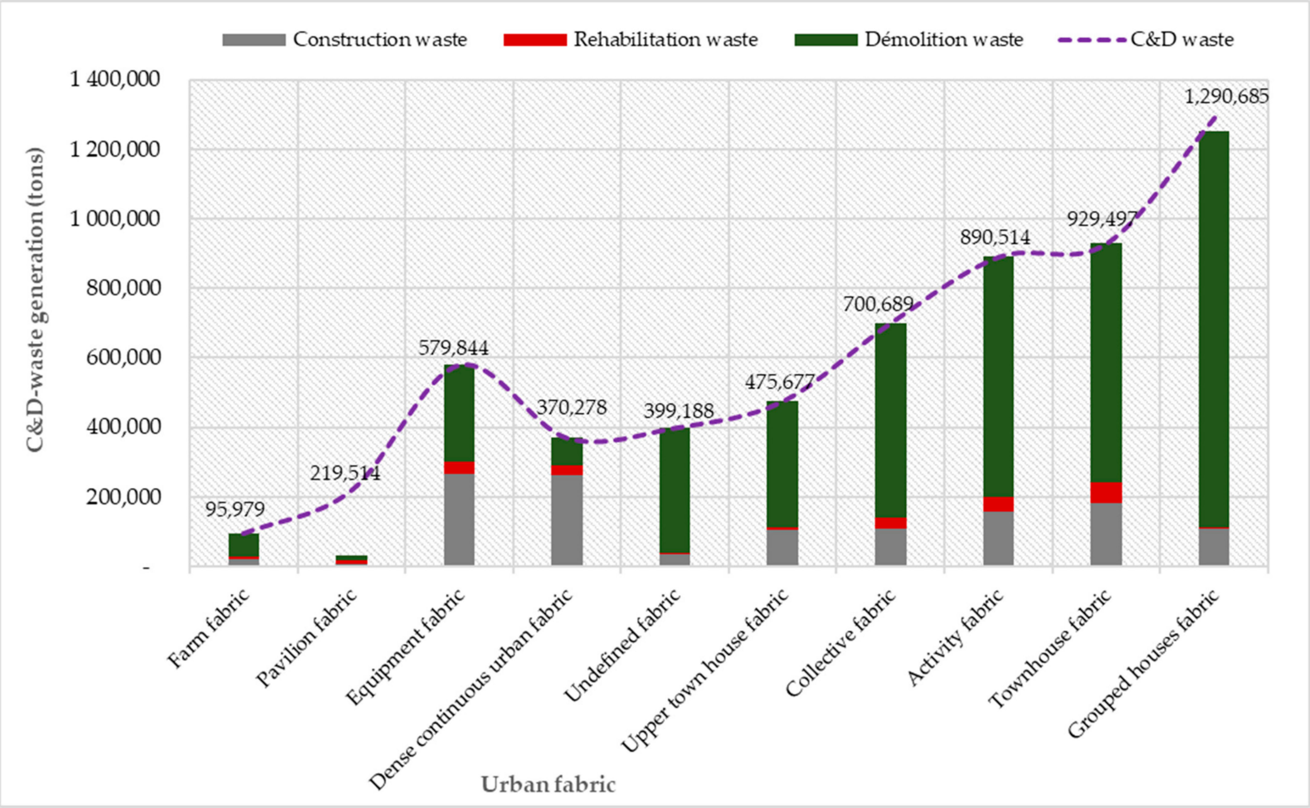


Figure 3. CDW generation by urban fabric according to type of construction site from 2013 to 2022.

3.2.2. CDW Dynamics by Year and Type of Construction Site

Figure 4 summarizes CDW production per year between 2013 and 2022 for each type of construction site. On average, 600,000 tons of waste were generated each year in the MEL. Taken separately, rehabilitation and new construction sites produce the least waste. Construction generated an average of 131,842 t/year, rehabilitation 26,415 t/year, while demolition produced an average of 439,928 t/year. Each year, the proportion of demolition waste remains significantly higher than that generated by construction and rehabilitation sites. Similarly, rehabilitation generates less waste than new construction. During this period, the year 2021 generated the most waste, i.e., 947,229 tons. This dynamic may be linked to the revival of post-COVID-19 C&D activities, following their cessation in 2020. In fact, the projects scheduled for completion in 2020 were finally and/or probably carried out in 2021, which justifies the large amount of waste generated in 2021. For the rest of the years, the trends remain more or less the same, with the exception of 2022, which has incomplete data (4 months).

The analysis of the quantities of waste produced per year is very important, as it enables us to calculate the indicator of waste production per inhabitant and will serve as a basis for discussion with other sources.

In the previous sections, we presented the overall results of the quantification of CDW by urban fabric, by year and by type of construction site on the MEL between 2013 and 2022. In the following section, we go into more detail by presenting the quantities by type of material (concrete, tiles, metals, etc.) and by waste category (inert, non-inert, and hazardous).

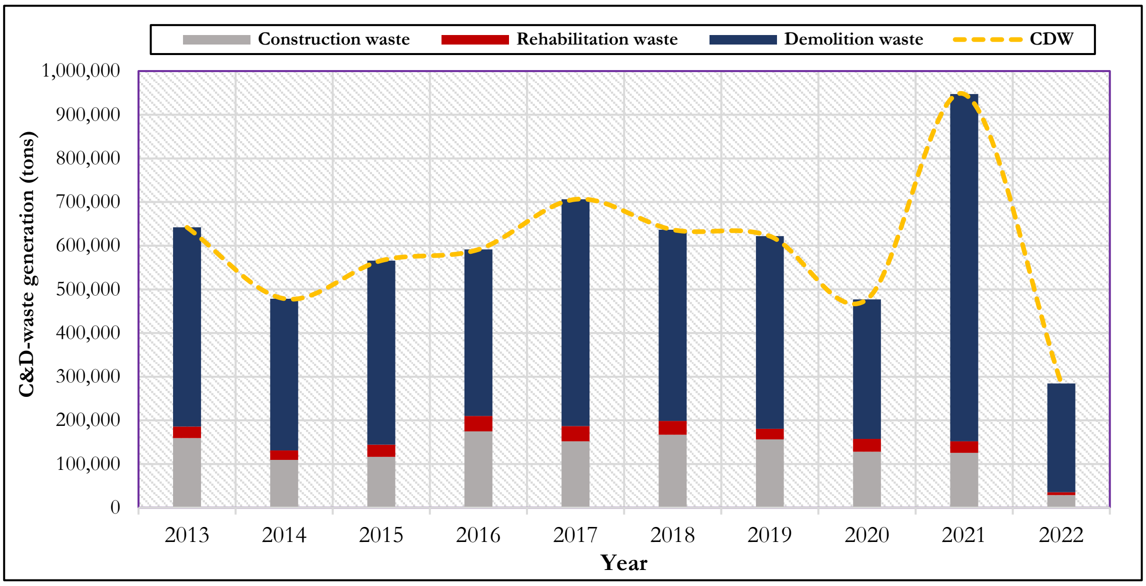


Figure 4. Breakdown of CDW production per year by type of site.

3.2.3. Composition of Material of CDW in the MEL

In the European Metropolis of Lille, 90% of deposits are composed of inert waste, compared with only 9% of non-hazardous waste and 1% of hazardous waste (Figure 5). This distribution follows the same trends at the national level. Here, however, it is highly dependent on the source data used to estimate materials. The waste diagnostics and PEMDs obtained contained little data on hazardous waste, which justifies this significant discrepancy.

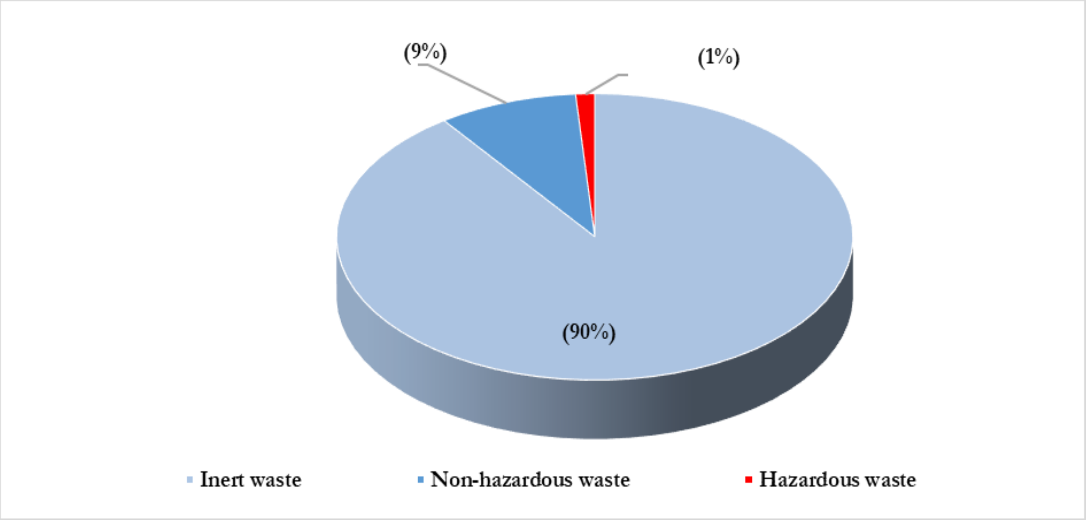


Figure 5. Distribution of CPMB waste typology in the MEL.

Table 5 shows in detail the quantities of waste in tons by type of material for the different sites. Inert waste consists mainly of concrete and stone, bricks, and tiles. These materials alone account for more than 85% of total waste. The largest deposits of materials come from demolition and construction sites.

Table 5. Breakdown of the quantity of CPMB waste by type according to worksites in the MEL over the period 2013–2022.

Cat	Waste Type	Construction Waste	Rehabilitation Waste	Demolition Waste	
Inert waste	Bituminous mixtures (without tar)	3876	1185	20,094	3,935,418 tons (90%)
	Uncontaminated soil (excluding topsoil)	0	0	0	
	Concrete and stone	579,305	126,255	2,110,130	
	Tiles and bricks	569,011	105,327	1,705,964	
	Ceramics (tiles, earthenware, and sanitaryware)	9373	1580	28,769	
	Glass without joinery	404	91	1654	
	Mixtures of the above listed waste materials without NHW	17,857	3060	53,184	
	Other inert waste	4361	965	15,623	
Non-hazardous waste	Plasterboards and tiles	14,820	3506	57,135	381,856 tons (9%)
	Gypsum plaster—inert substrate	2692	775	13,159	
	Plaster-insulating compounds	5212	818	13,561	
	Untreated wood	6512	1218	22,602	
	Low-additive wood	12,600	2044	33,278	
	Windows and other glazed openings	815	172	2718	
	Metals	15,568	3994	69,403	
	Plastics-exPVC	425	70	1472	
	Insulation-Mineral wool	878	250	4247	
	Insulation-Foamed plastics (EPS, XPS, PU)	369	68	1351	
	Insulation-Other	189	39	648	
	Tar-free waterproofing compounds	3468	525	9199	
	Floor coverings	262	59	933	
	Non-hazardous WEEE (2)	72	22	374	
	Mixtures of NHW	8197	1188	20,560	
	Plants	110	34	570	
	Topsoil	27,332	3947	69,309	
	Other NHW	21,227	3909	61,336	
Hazardous waste	Asbestos bound to inert materials	5908	1113	18,907	52,014 tons (1%)
	Other types of bound asbestos (3)	2646	539	9272	
	Friable asbestos	407	125	2112	
	Bituminous mixtures containing tar	16	2	32	
	Waterproofing compounds containing tar	0	0	0	
	Paints containing dangerous substances	1	0	3	
	Treated wood containing dangerous substances	25	4	64	
	Heating, air-conditioning or refrigeration equipment containing hazardous refrigerants	9	3	47	
	Light sources (fluorescent tubes, neon lights, discharge lamps, LED lamps)	2869	870	14,752	
	Other WEEE (2) containing hazardous substances	142	31	492	
	Soil containing hazardous substances	0	0	0	
	Other HW	1466	371	6333	
	Total (tons)	1,318,422	264,159	4,369,288	

3.3. *Analys of MEL's Dependance of PMCB*

The analysis of the territory's dependence on CBMP waste from deconstruction will be carried out in two stages. The first stage concerns the inter-annual dynamics between resources (usable materials from demolition) and construction material requirements. The second stage consists of studying the rate of coverage of MDPE resulting from deconstruction in relation to the needs in CBMP of each municipality. The coverage rate represents the percentage of substitution of new materials by materials from the demolition of buildings. This step enables the analysis of the urban mining potential of metropolitan areas by calculating for each municipality the rate of coverage of new construction materials (primary materials) by secondary primary materials from demolition.

3.3.1. Temporal Analysis of the Dynamics between Needs and Resources from 2013 to 2021

Figure 6 offers an initial analysis of the urban mining potential within the MEL. It underscores the quantitative disparities between the demand for building materials and the resources derived from building demolition on an annual basis. Overall construction material requirements average 1,580,000 t/year while demolition (resources) produce an average of 629,000 t/year. However, if we consider the recovery/recycling target set by ADEME (the French Environment and Energy Management Agency) of 90% of total CBMP deposits, the average production would be around 580,000 t/year. This means that the average annual coverage rate of new construction materials by demolition waste is 35.82%. If the current rate of recycling and reuse is considered which is 75% [2] the average annual coverage rate falls to 29.85%. It should be noted that the assumption or objective pursued by the administrative authorities is that in the long term 80% to 100% of EDPs will be replaced by new construction and building products and materials.

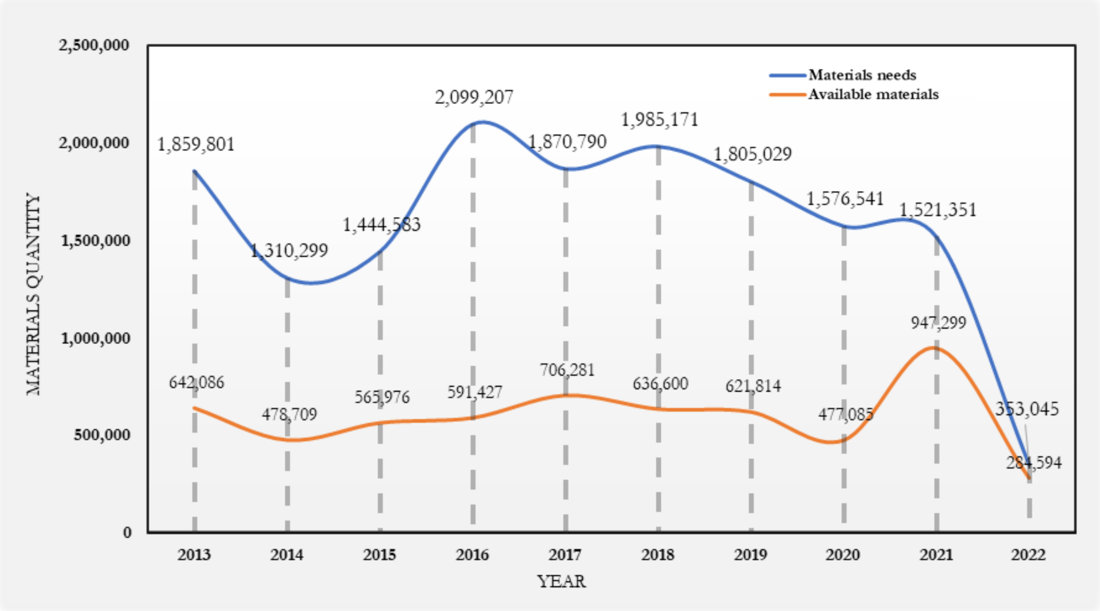


Figure 6. Evolution of the quantity of materials (t) between needs and resources per year in the MEL Needs correspond to an estimate of materials based on the analysis of building permits and consistency with GIS data; Resources represent the PEMW from demolition, rehabilitation, and construction, which could potentially be substituted for CPMB.

A detailed analysis of Figure 6 shows that, in all years, material requirements remain significantly higher than resources. For example, the rate of coverage of EODM from deconstruction is 28% in 2016, 37% in 2017, and 30% in 2020. However, 2021 is an exception. The gap between resources and needs is narrowing (or is smaller) compared with the other years. This trend is justified by the decrease in the volume of construction materials in 2021 and the increase in deposits from building demolition in the same year. As 2020 was marked by COVID-19, all C&D worksites had been halted. It can be therefore assumed that most of the work scheduled for 2020 was actually carried out in 2021, which justifies the increase in CPMB waste. Waste from the demolition of buildings would make it possible to cover more than 62% of construction material requirements, with the hypothesis that 100% of CPMBs are reusable, reusable, and/or recyclable. It is worth noting that the term “waste” has become overused and that the term “resources” will have its place in the years to come!

3.3.2. Territorial Analysis of the Rate of Coverage of CBMP in the MEL

The dynamics between available resources and construction material needs were also observed and analyzed at the territorial level. The aim is to study the dependence of each municipality on CPMB waste. A spatial analysis using GIS was used to allocate to each locality the quantities of materials from demolition and the requirements for construction materials. It should be remembered that building material requirements were calculated based on building permit data. The detailed results of this analysis are presented in Table S4 (see the Supplementary Material Section).

The analysis of the dependence of the territories on the CPMB shows two dynamics overall, which depend on the characteristics or typologies of the territories. The dynamics of materials production differ according to whether the area is urban or rural, and corroborate the conclusions of ref (Gao et al., 2020) [32], in their article entitled "Dynamic material flow and stock analysis of residential buildings by integrating rural-urban land transition". In rural municipalities, the resources–needs balance is largely in surplus. Materials from the demolition of buildings (resources) far exceed the need for construction materials (Table S4). Five (5) municipalities are concerned. These are Wervicq-Sud, with an estimated coverage rate of 552%; Lompret, 483%; Wicres, 125; and Bondues and Wattrelos with 105 and 104%, respectively. In addition, 10 municipalities have a substitution rate between 95% and 50%, including Carnin (95%), Willems (62%), and Hellemmes (52%). In addition, 26 municipalities, including Lille, have a coverage rate of between 49% and 30%. All the other fifty or so municipalities have a substitution rate between 29% and 10% (Table S4).

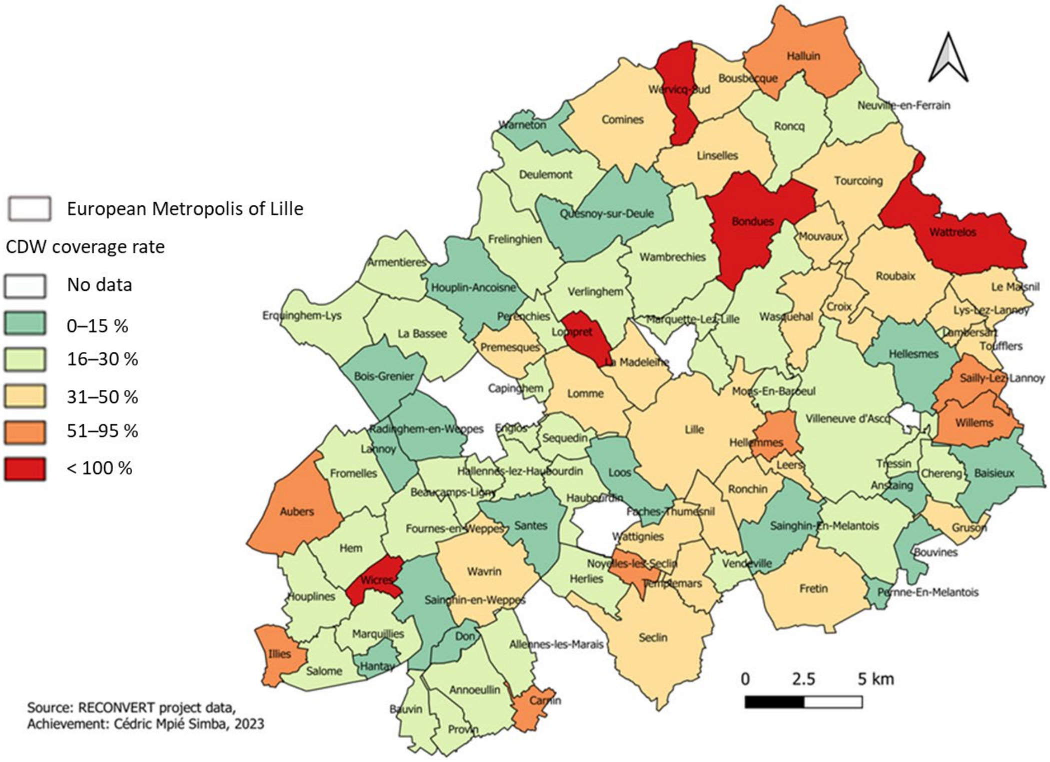
The Table S4 shows that over 95% of the regions experience a shortfall, where the quantitative requirements for construction materials exceed the resources that are potentially available. Regional analysis indicates that if CBMP waste is recovered, it could cover 41% of the total construction material requirements. Consequently, the region remains 59% dependent on new materials. This overall coverage rate of 41% is significant, suggesting that the use of primary (new) materials could be nearly halved if waste from building deconstruction is maximally reused and recycled. This approach would help to reduce pressure on primary resources and the environment, which are currently major concerns, while also promoting local employment.

There is a negative trend between the number of inhabitants per km^2 and the rate of coverage of CPMB waste in the regions. In fact, the coverage rate is lower in densely populated areas and vice versa. In other words, the resources–needs balance is very negative (needs being greater than resources) in highly urbanized areas, whereas it is positive in sparsely populated municipalities. However, these surpluses need to be put into perspective, as the quantities of demolition waste in these areas are much lower than in areas with a deficit. For easier reading, the data from Table S4 have been represented and summarized on a map (Figure 7). For each municipality, it shows the potential for substitution of new construction materials by demolition waste.

In addition, another mapping makes it possible to analyze and/or observe the dependence of the MEL on the CPMB. Thus, the different volumetric flows were spatialized and represented cartographically (Figure 8). We can see the predominance of needs for construction materials in almost all municipalities compared to resources from deconstruction.

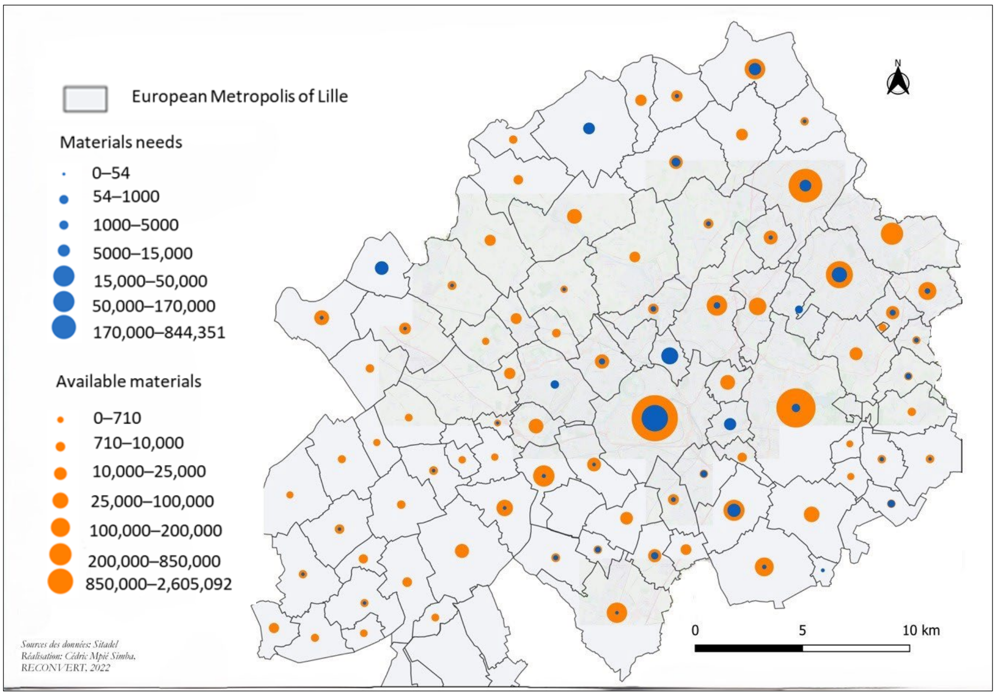
Several lessons can be drawn from these maps and tables. Firstly, they serve as important decision-making aids for efficient waste management that city policies could promote. For example, they could help refine local circular economy policies and effectively combat material wastage [33,34]. The results of this analysis, particularly Table S4 and Figures 7 and 8, highlight that some areas lack data. Further investigation is required, especially with local councils, to understand the absence of building permits for deconstruction over a 10-year period.

However, the maps produced can make a practical contribution to guiding decisions on the siting of new platforms and storage centers for materials to be reused and recycled in the MEL area. This can encourage a better compromise between the distances to be covered in existing sites and areas to be excluded (natural, sloped, ultra-urban, etc.). They are, therefore, a first step towards a better understanding of the EPR (Extended Producer Responsibility) sector and its territorial network in the MEL area, as well as the resulting needs (Table S4).



Source: RECONVERT project data,
Achievement: Cédric Mpié Simba, 2023

Figure 7. Rate of substitution of new construction materials by C&D waste by municipality.



Sources des données: Sitadel
Réalisation: Cédric Mpié Simba,
RECONVERT, 2022

Figure 8. Spatial distribution of CPMB volumetric flows in the MEL between 2013 and 2021.

3.3.3. Comparative Analysis of Quantification Results

A comparative analysis was carried out to compare our waste quantification results with the official data produced at the national and European level (Table 6). The comparative approach is based on the determination of an indicator of waste production per person per year. This indicator is obtained using the production rate calculation method (GRC), in this case the per capita multiplier. This is based on the average production of waste per person in tons per year, to calculate the stock of waste in an area. In total, we compared our data with four other sources, two at the local level (France) and two at the European level. Indicators of waste production on a European scale have been identified in the literature. These are Eurostat data for France and the average waste production per person per year calculated in relation to the total population of 28 EU countries [35]. The authors used the indicator that covers the waste category 'Mineral waste from construction and demolition' (EWC-Stat 12.1).

In Table 6, for the indicator identified as "EWC-Stat 12.1_EUROSTAT", only non-hazardous waste is taken into account, (see https://data.europa.eu/data/datasets/uczdo4z1o5qcllbdtbkhq?locale=en, accessed on 1 January 2024).

It should be noted that the waste production indicator is the ratio of the total quantity of waste to the total population of an area. This indicator has been calculated for national data (see in refs. [2,22,23,35]) for our data (RECONVERT). Thus, the total quantity of waste produced per year in France as part of the EPR-CPMB channel project [2,23] i.e., around 43 million tons, divided by the total population, yields an indicator of 635 kg of waste per person per year (i.e., 0.635 t). This value is virtually the same as that obtained for the building demolition project carried out by ADEME, i.e., 610 kg/year/person (Table 6). At the European level, the data provided by Eurostat for France yield an indicator of 437 kg, while the overall average waste production per person, again according to Eurostat, is 481 kg. It should be noted that in all these studies, the indicators calculated do not consider all building waste. They are generally based on the main types of waste in inert waste. As part of the RECONVERT project, we used a wider range of waste than other sources, notably ref [23] (ADEME_2020, EPR-CPMB_2021 channel), and EWC-Stat 12.1_EUROSTAT. Finally, differences between data from different sources may be linked to the level of precision, the scale of analysis, and even the method of quantification.

In addition, the value of the multiplier per inhabitant that we obtained (RECONVERT), is very close and remains in the same trend as the official national or European data (Table 6).

Table 6. Comparative table of waste production indicators according to data sources, by using per capita multiplier.

Data Source	Scale	Waste per Capita (kg)	Waste Quantity (t/Year) in the MEL
RECONVERT (us)	Local	564	661,318
EPR-CBMP channel_2021	National	635	743,885
ADEME_2020	National	610	714,075
EWC-Stat 12.1_EUROSTAT	National	437	511,565
European average for EWC-Stat 12.1	European	481	563,073

The results of the calculation of the indicators according to the sources are presented in the table above. The total quantities of waste per year in the MEL are obtained by multiplying the value of the indicator for each source by the total population of the MEL. The comparison of our data with the official data produced at the national level is satisfactory. The quantification methodology we have adopted produces results that are virtually in line with the trends in the official data. The method used can therefore be applied to other areas or territories, provided that the necessary data are available.

4. Discussion

The methodological approach adopted in this document has made it possible, on the one hand, to quantify CPMB waste deposits on several scales and, on the other hand, to obtain very satisfactory results. It is mainly based on the production rate calculation method and focuses on calculating surface area and determining the average weight of each type of material. The calculation of quantities is heavily dependent on actual historical data from the various construction and demolition sites. Data sources, particularly the quality of waste and PEMW diagnostics, inevitably play an important role in the accuracy and robustness of the results. Further surveys are to be carried out, and the establishment of the REP CPMB in France, coupled with our methodology for matching building and demolition permits in each area, will enable us to refine these results for each region and urban fabric in the near future. An approach based on the age of the building could also be put in place to assess its potential or chance to be deconstructed or renovated.

Unlike other approaches, we placed particular emphasis on the specific nature of urban fabrics and considered a range of waste products and materials from the construction and building sector. We used data from construction and demolition permit forms allocated in the MEL territory between 2013 and 2022 to estimate the quantity of CDW. The C&D databases created in this way made it possible to obtain actual data on the surface areas demolished and constructed. Using the data from the waste and PEMW diagnostics collected from players in the building deconstruction sector, we were able to calculate the unit weight in tons/m^2 for each type of material. A GIS analysis was used to classify data from demolition sites and permits by urban fabric. In this way, an indicator of waste production by type of material (unit weight of waste per unit area) was determined for each urban fabric. Following this processing, the quantities of CDW were estimated using the GRC method, in particular the calculation based on surface area. The data were then extracted by type of urban fabric, by year, by material, and by locality.

The spatial and temporal distribution of the various sources has enabled us to make an introductory analysis of MEL's dependence on CPMB waste. Firstly, the analysis of inter-annual dynamics showed that each year, demolition and construction waste can cover on average between 29 and 35% of MEL's construction material requirements. Secondly, substitution rates for CPMB waste were determined on a territory-by-territory basis. Here, the rate of coverage varies according to the typology of the territories and is highly dependent on population density. For more than 95% of municipalities, resources from building demolition are still lower than construction material requirements. The overall results show that waste (considered as a "resource") generated in MEL areas can cover 41% of construction material requirements.

Furthermore, despite the good results obtained, a few points of discussion can be addressed. The first concerns the source data collected from the players and their breakdown by urban fabric. The MEL has nine urban fabrics. But the data collected covered only five fabrics. What is more, the number of buildings or worksites varies from one urban fabric to another. Some waste diagnostics or CPMB have a higher number of buildings than others. These facts weaken the statistical results for unit weights of materials in these urban fabrics. What is more, some diagnoses contain more materials than others. In several forms, the quantities of certain types of waste were not included, nor were the surfaces demolished. To make up for these shortcomings, and to obtain robust data, it is necessary to have real data covering all types of fabric and to have a common sample (same number of building sites) for all types of urban fabric, which is virtually impossible to obtain or achieve today. In addition, to be more relevant, the worksite data used to calculate unit weights must be representative of the MEL territories. Although the data used are that of the territory, they only concern around 10 of the 95 communes. Further work could therefore be carried out to pursue this initial approach. Finally, further investigation is required, particularly with the local authorities, to understand the absence of deconstruction and/or building permits over a 10-year period.

These areas for improvement have little impact on the quality, accuracy, and conclusions presented. The results of this study provide information on the urban mineral potential of the municipalities in the Lille European Metropolis. For each territory, it provides the rate of dependence on CPMB by estimating, on the one hand, the deposits or stock of materials available and by calculating, on the other hand, the quantities of materials required for the construction of new buildings. One of the specificities was the calculation of the quantitative requirements in construction materials. In the literature, the quantities of incoming materials are generally estimated either by extrapolating the financial value of the materials, or by estimating the total quantity of new materials placed on the market during a given period. In our case, however, we have used building permit data. We feel that this approach is more relevant because it considers the specific nature of the fabric in each region.

5. Conclusions

The aim of this study was to quantify the waste generated by building construction and demolition materials, using a territorialized spatial analysis based on data from waste diagnostics and CPMB, coupled with driving and demolition permits. The dynamics of building construction and demolition were first assessed through a historical analysis based on the use of geographic information systems. A link was then established between the dynamics of building construction and demolition and the potential for CPMB waste production by locality. This made it possible to identify the areas most likely to generate CDW.

These results have made it possible to study certain elements of the urban metabolism of the European metropolis of Lille, notably through the study of incoming and outgoing flows. It was found that the need for construction materials, determined from building permits, was much higher than resources from building demolition.

Data derived from the estimation of CPMB waste quantities per year, per municipality, and per urban fabric, provide information on the urban mining potential of each municipality. We have thus located areas with high or low potential and determined for each commune the potential rate of substitution of new materials (primary materials) by those from demolition (secondary primary materials). Overall, our estimates show that CDW could cover 1/3 of MEL's construction material needs. They show that this territory has a significant potential (deposits) for developing a circular economy policy based on the reuse and re-utilization of CPMB.

The results obtained in this article provide important elements of knowledge, which can be further developed and exploited to meet resource conservation and environmental objectives through the implementation of circular economy policies. The reuse of materials from building demolition can make a significant contribution to limiting pressure on primary resources, and to protecting the environment. The results obtained here are intended to help decision-making. They provide new, in-depth local knowledge of available deposits. This knowledge can be used to support and/or guide CDW management policies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/resources13060076/s1, Table S1: Classification of the Methods. Source: [3]. SV: Site Visit method; GRC: Generation Rate Calculation method; GIS: Geographic Information System; BIM: Building Information Modeling; VM: Variables Modeling method; CSA: Classification System Accumulation method; MFA: Material Flow Analysis approach; PL: Project level; RL: Regional level; Table S2: Waste production indices (t/m^2) according to the urban fabric of the MEL. FF: farm fabric; PF: Pavilion Fabric; AF: Activity fabric; SDGHF: Fabric of semi-detached or grouped houses; DCUF: Dense continuous urban fabric; TF: Townhouse Fabric; CF: Collective fabric; UTHF: Upper town house fabric; EF: Equipment fabric; UF: Undefined fabric; Table S3: Share of surface area built, renovated, and demolished by municipality between 2013 and 2022; Table S4: Volumetric breakdown of material requirements and available resources by municipality; Table S5: Table of abbreviations. References [36–40] are mentioned in the Supplementary Materials.

Author Contributions: Conceptualization, E.L.; methodology, E.L. and C.M.S.; software, C.M.S.; validation, E.L.; formal analysis, E.L. and C.M.S.; investigation, E.L. and C.M.S.; resources, E.L. and C.M.S.; data curation, C.M.S.; writing—original draft preparation, E.L. and C.M.S.; writing—review and editing, E.L. and C.M.S.; visualization, C.M.S.; supervision, E.L.; project administration, E.L.; funding acquisition, E.L. All authors have read and agreed to the published version of the manuscript.

Funding: We sincerely thank the European Metropolis of Lille and the University of Lille for funding the RECONVERT Industrial Chair led by IMT Nord Europe.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: We sincerely thank the partners of the RECONVERT chair for providing data on product diagnostics, equipment, materials, and waste from deconstruction sites. We acknowledge the use of ChatGPT 3.5 (Open AI, https://chat.openai.com, accessed on 20 April 2024) to improve the English quality of this publication (please see the Materials and Methods Section).

Conflicts of Interest: The authors declare no conflicts of interest.

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