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Circular economy indicators for buildings and housing

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Circular economy indicators for buildings and housing

PUB. N° 19

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Summary

This report presents a Circular Economy monitor for the societal need fulfillment system of buildings and housing. It is part of the CE monitor of the policy research center. The indicators of this monitor were compiled like reported to reflect the circular economy including its economic, environmental and societal aspects.

The indicators show that a single building or housing unit might seem circular at first glance. For example, the recycling rates of the majority of construction materials are high, the average lifetime of buildings is increasing, and the heating efficiency of residential houses is increasing. However, the need fulfillment system in its entirety is not circular yet. In Flanders, built areas are still expanding at the cost of natural land and wildlife habitats. More virgin raw materials are excavated for the building sector than secondary raw materials are delivered from the recycling routes. Down-cycling, thus the loss of material quality in the recycling route, is common practice. Data on non-residential buildings, building material compositions, end-of-life processes, and impacts of buildings and housing on society are missing vastly.

This report shows the widespread data sources necessary for a CE monitor, ways to improve data quality for the indicators, and gives suggestions for new data demands for a more insightful monitor. Collaborative stakeholder interaction was crucial to compile this monitor and it will be essential to further develop the presented indicators and to expand the indicator set.

Samenvatting

In dit rapport wordt een circulaire economy monitor voor het behoeftesysteem gebouwen en huisvesting voorgesteld, als onderdeel van de CE monitor ontwikkeld binnen het Steunpunt Circulaire Economie. Zoals toegelicht in het rapport werden de indicatoren van deze monitor gekozen om de circulaire economie voor te stellen met inbegrip van economische, milieu- en maatschappelijke aspecten.

De indicatoren tonen dat een afzonderlijk gebouw of huis op het eerste zicht circulair zou kunnen lijken. De recyclagegraden van de meerderheid van de bouwmaterialen zijn bijvoorbeeld hoog, de gemiddelde leeftijd van gebouwen stijgt en de efficiëntie van verwarming van residentiële woningen neemt toe. In zijn geheelheid is het systeem echter nog niet circulair. In Vlaanderen breidt de bebouwde oppervlakte zich nog steeds uit ten koste van natuurlijk land en habitats van dieren in het wild. De hoeveelheid nieuwe grondstoffen die wordt ontgonnen neemt sterker toe dan dat secundaire grondstoffen kunnen aangeleverd worden vanuit recyclage. Downcycling, het verlies van kwaliteit van materialen tijdens recyclage, komt vaak voor. Verder is er een groot gebrek aan gegevens over niet-residentiële gebouwen, samenstellingen van bouwmaterialen, processen aan het einde van de levensduur en over de maatschappelijke impact van gebouwen en huisvesting.

Dit rapport toont dat de data nodig voor een CE monitor wijd verspreid zijn, wijst wegen aan om de kwaliteit van data voor indicatoren te verbeteren, en geeft aanwijzingen voor waar er data nodig zijn om meer inzichtelijk te kunnen monitoren. Collaboratieve interactie met stakeholders was cruciaal om deze monitor samen te stellen, en het is essentieel om de voorgestelde set van indicatoren verder te ontwikkelen en uit te breiden.

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AB	Apartment Block
BMZ	Federal Ministry for Economic Cooperation and Development Germany (Bundesministerium für wirtschaftliche Zusammenarbeit)
CE	Circular Economy
CF	Carbon Footprint
CO_2eq	Cabon-Dioxide-Equivalent
COICOP	Classification of Individual Consumption by Purpose
DBRIS	Belgium commercial register
DPSIR	Driving forces-Pressure-State-Impacts-Responses framework
EEA	European Environment Agency
EORA	Eora global supply chain database by KGM & Associates
EPC	Energy performance certificate
EU	European Union
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ha	hectare
HMRP	High environmental risk profile rubble
IEE	Institute of European Studies
IIASA	International Institute for Applied Systems Analysis
kton	kilotons (metric)
kWh	Kilowatts-hour
LMRP	Low environmental risk profile rubble
LNE	Departement Leefmilieu, Natuur en Energie (now Departement Omgeving, OMG)
m^2	square meters
m^3	cubic meters
MF	Material Footprint
MFH	multi-family house
MJ	Megajoules
NACEBEL	Belgium variant of the NACE code
OECD	Organisation for Economic Co-operation and Development
OVAM	Public Waste Agency of Flanders
PJ	Petajoules
PM	Particular Matter
SFH	single-family house
t	tons (metric)
TH	terraced house
VEKA	Flemish Energy and Climate Agency
VITO	Flemish Institute for technical research
VMM	Flemish Environment Agency
VMSW	Flemisch Agancy for Social Housing
WHO	UN World Health Organisation
yr	year
µg	micro-gram

Circular Economy indicators for buildings and housing

1. Introduction

The region of Flanders aims to have a circular economy by 2050 (Vlaamse Regering, 2016). The Policy Research Center for Circular Economy (Steunpunt Circulaire Economie) develops a monitor to record the circular economy in Flanders. The major purpose of this monitor is to evolve significant and useful indicators guiding the transition from the linear to the circular economy. This study is a part of a research line started in 2017.

First, the conceptual framework of systems to fulfill societal needs was developed within the Policy Research Center. This system helps to analyze material flows, caused emissions, and societal impacts based on the fulfillment of needs (Alaerts et al., 2019). The basic idea of the framework is that the economy is an instrument to satisfy societal needs by offering products and services. These products and services have to be studied in more detail first before policymakers can encourage changes towards the circular economy. Thus, the monitor serves as a feedback instrument for policymakers.

A set of indicators is needed to reveal underlying processes. Figure 1 shows that three levels of indicators can be defined: macro, meso, and micro. Macro indicators display impacts and effects over the whole region of Flanders. On the other hand, micro indicators reflect the product, service and company level. Meso indicators summarize products and services belonging to the same need fulfillment system. So, the meso level combines information from the macro and micro levels to provide a more detailed but yet useful and representative insight into specific region-wide domains. This allows including more developed, sustainable strategies, i.a. product as a service, in the monitoring.

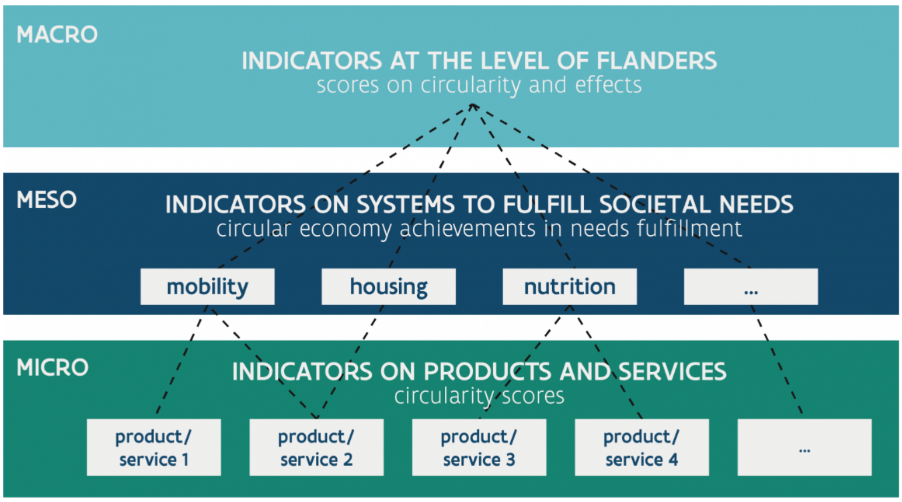

Figure 1: Overview of the level of indicators and the CE monitor (Alaerts et al., 2019).

At first, the Policy Research Center Circular Economy focuses on mobility, consumer goods, housing, and nutrition. These four domains were chosen, primarily because about 90 % of the material and carbon footprint of Flemish households can be allocated to them (Raes, van Pelt, et al., 2020; Vercalsteren et al., 2017). In their studies, (Alaerts et al., 2020) and (Vermeyen et al., 2021) already investigated the need fulfillment system of mobility and the fulfillment system of consumption goods, respectively. Consequently, this study focuses on the fulfillment system of buildings and housing.

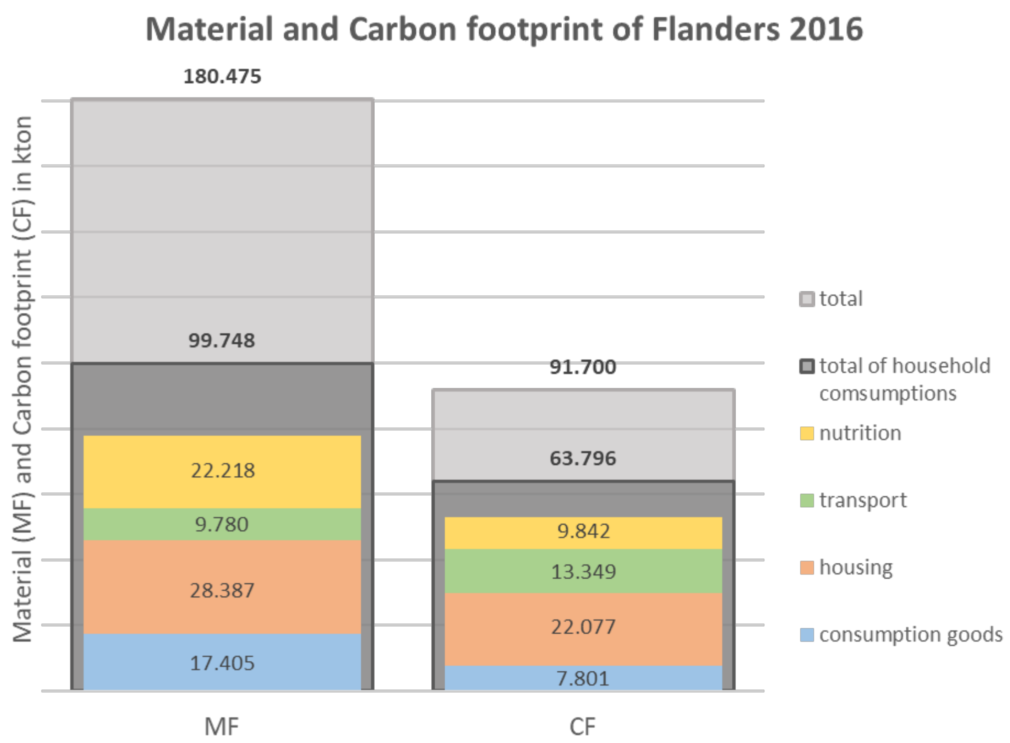

Figure 2: Material footprint (MF) and Carbon footprint (CF) in total and of household consumption in Flanders 2016 (in kton) (Christis et al., 2021).

This study aims to provide a set of indicators showcasing the current state of the building and housing system from a circular economy perspective. Based on the need fulfillment systems, the building and housing need system includes products like housing units (i.a. apartments single-family houses, terraced houses), retail space (i.a. shops), logistics space (i.a. warehouses), offices, production plants, upkeep of the real estate, lighting, heating, etc. It excludes pavements for streets, railroads, mobile homes, consumer goods (i.a. kitchen ware, washing machines, white and brown goods), etc., as they are part of other need systems. It is a first attempt to set up a CE monitor for buildings and housing in Flanders. Thus, it will try to implement the framework's concepts for this domain demonstrating the insights and challenges of drafting a set of indicators measuring the circular economy.

2. Compilation of the indicators

In every monitor, it is crucial to understand why and how the monitor's indicators were derived. The indicators should cover the whole need system and, thus, give more detailed insights. On the other hand, the indicators should be significant and summarizing at the same time. Those partly contradicting expectations result in challenges while compiling indicators for the monitor. Schemes and frameworks help to establish a comprehensive and insightful set of indicators.

In the reports on consumption goods (Vermeyen et al., 2021), and personal mobility and transportation (Alaerts et al., 2020), the indicators were developed on the principles of data availability and stakeholder workshops. As this approach relies on snap-shots of data supply and workshop participants, alternating sets of indicators between different need fulfillment systems or unconsidered, but insightful, indicators might be the result. To mitigate those aspects, a more structured approach was attempted in this study. The conceptual framework of systems to fulfill societal needs, developed by (Alaerts et al., 2019), was used to define the borders between the different need fulfillment domains. To compile suitable indicators within the building and housing need system, this study uses the so-called DPSIR Analytical Framework (Hák et al., 2007), developed by the European Environment Agency (EEA) based on an OECD model. This framework was developed to help design assessments, identify indicators, communicate results, improve environmental monitoring, and collect information.

(Ness et al., 2010) applied the DPSIR framework to define indicators within the system of nested domains, described by (Hägerstrand, 2001). They reported that the DPSIR framework helped them to structure causal relationships at each policy level systematically. Thus, the DPSIR framework can be applied within a bigger, framing system. Also, (Holman et al., 2008) based their considerations for their regional assessment tool on the DPSIR framework. (Carr et al., 2007) reported that the DPSIR framework is useful for assessing sustainable, regional development if the aggregated outcomes of local are taken into account in the framework. In the context of this study, driving forces can be translated into the needs, and the pressure and impact categories correspond to the effects section in the CE monitor's context. Based on the previous works and the alignment with the system to fulfill societal needs, the application of the DPSIR framework seems to suit perfectly compiling the indicators for the building need fulfillment system.

The explicit aim of the DPSIR framework is to support monitoring environmental actions set by policymakers. For this purpose, the framework uses the concept of driving forces, pressures, state, impacts, and responses to structure thinking about the interplay between the environment and socioeconomic activities (Hák et al., 2007). Figure 3 is an overview of the framework's indicator chain. Every category highlights an important aspect on the policy point of view:

- Driving forces indicators reflect social, demographic and economic evolutions which cause changes in consumption and production patterns; e.g. population or economic growth.
- Pressure indicators describe the release of emissions into the environment and the use of resources or land, caused by the driving forces; e.g. kilogram of CO_2 emissions.

- State indicators measure the quality or quantity of a certain area in physical, chemical, biological means; e.g. air temperature, CO_2 concentration, or the number of animals.
- Impact indicators illustrate the importance of the changing state of the environment. Thus, it numbers the share of people or animals affected by environmental pollution, e.g. number of people starving because of droughts.
- Response indicators quantify the actions undertaken by society or governments to prevent, adapt or compensate for changes in the state of the environment. These responses might either limit or redirect the driving forces (e.g. consumption or production), or promote a rising efficiency of products or processes, e.g. recycling rates of waster or number of registered cars fulfilling the emission standards.

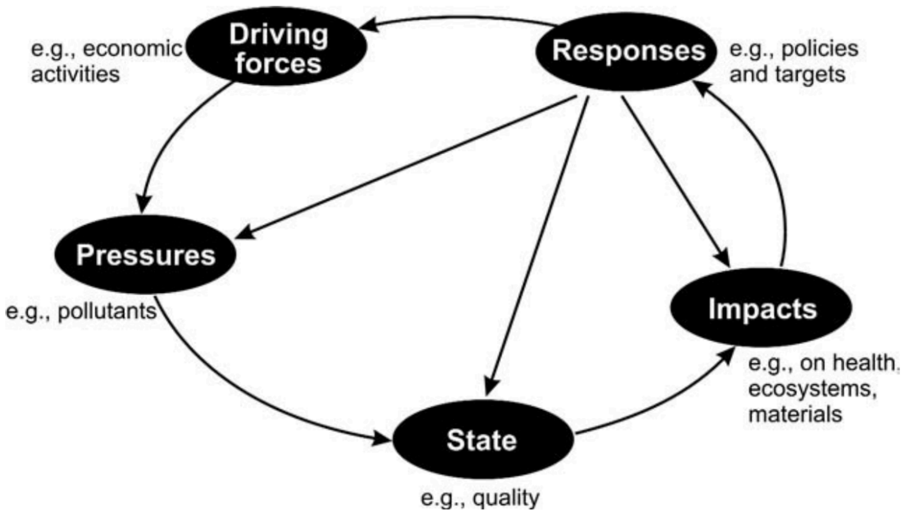

Figure 3: DPSIR Analytical Framework of the EEA (Hák et al., 2007).

The following subsections describe which considerations were taken into account while compiling the indicators for the building and housing need system. In the end, Figure 4 provides an overview of all indicators for the building and housing CE monitor.

Driving force indicators (D)

The driving force indicators should reflect the causes for the growing need for buildings. Of course, buildings provide shelter from the weather and provides storage and working space. Thus, the number of households (D1) indicates how many housing units are demanded, which reflects an increasing number of family houses or apartments. On the other hand, the driving force of companies' need for buildings is harder to number. One might think of the Gross Domestic Product (GDP) as an indicator of economic growth. However, economic growth can also be achieved by providing services or trade, e.g. online, which does not require an expanding office or production space while economic success. However, parallel to the number of households, the number of enterprises in Flanders (D2) was chosen to provide an insight into the potential need for commercial space, although a better indicator should be developed in this regard. Additionally, the total square meters of residential (D3), non-residential (D4), and of all buildings (D5) were chosen to reflect the size of the need system for buildings.

Pressure indicators (P)

A building, as the demanded item of the need system, is a very complex product. It consists out of several material types and uses a fair amount of space over a long period. Erecting a building asks for tons of building material, e.g. bricks, concrete, steel, and window glass. Of course, these building materials have to be produced from raw materials, e.g. sand, clay, or water, and by energy. The excavation of these virgin raw materials is pressure for the environment, and, thus, recorded in the monitor (P1). In this context, it should be the goal to measure the total material consumption as described by Eurostat or in (Christis & Vercalsteren, 2020). Also, the Carbon Footprint (CF) due to producing the materials, and erecting, using, repairing, and renovating the building (P2) should be recorded. Finally, the building also takes up some surface space. This surface then is sealed, displaces wildlife and natural habitats, and hinders water uptake of the floor after rain. Thus, the area of the built surface (P3) is also an important indicator of environmental pressure.

State indicators (S)
Following the logic, described for the pressure indicators, the state of the natural land of Flanders can be summarized by three indicators: tons of virgin raw materials, fuels and water reserves (S1), Emission concentration (S2), and area of natural land (S3). For sure, the values of these indicators are also affected by other need systems, e.g. the nutrition and mobility need system impact the area of natural land too.

Impact indicators (I)
To measure the impact of the building need system on humans and wildlife is hard. As the pressures and, thus, the impacts are manifold, often, they cannot be traced back explicitly to the building or construction sector. The impact of emission on human or wildlife health better be monitored by macro-indicators for whole Flanders. Because buildings demand water in their production chain and additionally seal surface space, the impact of water scarcity on the population (I3) seems to fit in this monitor. Besides environmental impacts, also social-economic impacts should be considered. In the case of buildings, homelessness (I1) is an evident issue to be tackled.

Response indicators (R)
In general, response indicators should trace the effectiveness of policies. Contrarily, this CE monitor should help initialize new policies. Thus, the set of response indicators proposed in this study should be seen as a start of an iterative process of constantly developing indicators following the emission policies. As mentioned earlier, responses either limit the driving forces or increase efficiency. In the building need system, the efficiencies respectively about raw materials (R1), surface usage (R2), square meter usage (R3), or heating (R4) should be recorded to lessen the pressures ultimately. As with every product, also long lifetimes of buildings can benefit environmental protection. Thus, renovations and repairs (R5) are preferred to new builds, which should result in a longer lifetime of buildings (R6). At the end of life, information is key. Due to more information about the demolition material, better and more effective treatments, e.g. reuse of elements or recycling, can be supported. In Flanders, the first initiatives of supervised demolition processes were established (R7). In a supervised demolition process, the materials are recorded and, thus, can be categorized by material type and traced easier. Ultimately, the recycling rate of the building material (R8) gives important insight into the circularity of the building need system.

Type	ID	Indicator description	Unit
Driving force (Need indicators)	D1	Number of households	#
	D2	Number of enterprises	#
	D3	Total floor area of residential buildings	m^2
	D4	Total floor area of non-residential buildings	m^2
	D5	Total floor area of all buildings	m^2
Pressure	P1	Tons of virgin raw materials, fuels and water excavated for buildings and housing	kton
	P2	Emissions emitted for buildings and housing	kton CO_2-Eq
	P3	Area of built surface	ha
State	S1	Tons of virgin raw materials, fuels and water reserves	kton
	S2	Emissions concentration (Air quality)	%
	S3	Area of natural land	ha
Impact	I1	Number of homeless people	#
	I2	Number of people affected by emissions	#
	I3	Number of people facing water scarcity	#
Response	R1	Raw materials efficiency (tons of raw materials used per square meter of buildings)	kton/m^2
	R2	Surface efficiency (square meters provided per surface area)	m^2/ha
	R3	Use efficiency (Occupancy rate)	%
	R4	Heating efficiency (avg EPC score)	kWh/m^2
	R5	Number of rented social housing units	#
	R6	Number of renovations and repairs	#
	R7	Average lifetime of buildings	years
	R8	Share of supervised demolitions	%
	R9	Recycling rates of building materials	%

Figure 4: Overview of the indicators for the building need system based on the DPSIR framework.

3. Data providers

This section will briefly explain the institutions, departments, and companies providing the major data sources for this study. While literature sources are cited in round brackets, the data resources are labeled with square brackets and continuous numbers and can be found at the end of this report. All data and results presented in this study are annual numbers specific for the Flemish region, otherwise, it is stated explicitly.

Statbel
Statbel, short for Statistics Belgium, is the major statistics institution of Belgium. It is part of the Federal Public Service Economy (FPS Economy) and provides statistics about many topics ranging from the population over energy to economy. Often, the statistic numbers are also available for the regions Flanders, Brussels, and Wallonia. For this study, the data about households, population, registered enterprises, number of buildings, construction permissions, and land use was retrieved.

TABULA project
The project of the IEE, called "Typology Approach for Building Stock Energy Assessment (TABULA)", is a bottom-up approach to provide a representative set of residential buildings for every member state. The project wants to measure the housing stock so the energy consumption for heating and cooling will be lowered. TABULA also offers a set of model buildings for open standing and terraced single-family houses (SFH), multi-family houses (MFH), and apartment blocks (AB) categorized by construction year class. In the case of Belgium, even semi-detached SFH are included. Every model building in the data set contains typical building properties, amongst others

- the construction period,
- the reference floor area,
- the energy need for heating,
- the needed energy carriers for heating,
- the CO_2 emissions caused by heating,
- the energy costs, and
- the existing type of construction in the buildings' elements roof, wall, floor, window, and door.

In the TABULA values list, more data about buildings' elements, their description, and their major material is retrievable.

Cushman & Wakefield Belgium
Cushman & Wakefield is a global consulting company, specializing in commercial real estate. Their Belgium branch publishes the report "Belgium MarketBeat", which evaluates the Belgian office, retail and semi-industry real estate market, quarterly. There are five series of the Belgium MarketBeat: Industrial Market Belgium, Retail Market Belgium, Regional Office Market Belgium, Office Market Brussels, and Office Market Luxemburg. For this study, the first three publication series were consulted to gain insights.

Metabolic's study

In 2020, the Economisch Instituut voor de Bouw (EIB), Metabolic, and SGS Search conducted a study modeling the urban mining model of the Dutch building sector. Useful data and insights were taken from this study, especially their calculated material composition of different building types.

OVAM, VEKA, VMM

The Public Waste Agency of Flanders (OVAM) provided several useful datasets, especially about commercial and household waste, the monitoring system for a sustainable surface minerals policy, and the production numbers of the rubble crushers in Flanders, to this study. The Public Energy Agency of Flanders (VEKA) publishes numbers about the energy consumption in Flanders on their homepage annually. This data was used to estimate the heating energy for buildings consumed. The Flemish Environment Agency (VMM) provides with its Environment Report, "Milieurapport", an extensive view on the situation of the nature in Flanders and was consulted mainly for data for the state indicators.

De Nationale Milieudatabase (NMD)

De Nationale Milieudatabase (NMD) (National Environmental Database) is a Dutch initiative to manage and maintain the data collection method and the associated database for determining the environmental performance of buildings and their maintenance. Thus, it provides open access to data about building elements and their material composition. In Belgium, a similar initiative exists, called Tool to Optimise the Total Environmental Impact of Materials (TOTEM). There, architects and housebuilders can model the planned building and calculate the Life Cycle Costs, thus it is an LCC software.

4. Results

The following subsections outline the data needs, the available data, and the identified data gaps for every compiled indicator described so far.

This study often differentiates between residential and non-residential buildings. In reality, a building can have several purposes, e.g. and multi-story building with a shop on the ground floor and apartments upstairs. Here, residential buildings are buildings offering housing units exclusively, while all the others are non-residential buildings. Thus, the multi-story example before will be classified as a non-residential building in this study. Another concept relevant to this study is the distinction between floor and surface area. While the surface area describes a piece of land occupied for a specific purpose, the floor area reflects the size of built structures. For example, an apartment block occupies 1.000 m^2 of surface area but its five equal-sized stories might offer 5.000 m^2 of floor area.

D1 Number of households

The first indicator of the set is the number of households in Flanders by year to enumerate the number of housing units demanded. As one of the most crucial statistics for governments, Statbel provides these numbers in its dataset "Aantal huishoudens volgens type" in the "Structuur van de bevolking" section [1]. The numbers are computed based on the national population register administered by the municipalities. They include all Belgians and foreigners with a registered residence permit and exclude Belgians living abroad, asylum seekers, citizens awaiting the registration, and citizens staying three months or shorter. Thus, the statistic does not reflect the actual number of people present in Flanders. Statistiek Vlaanderen also computes this statistic based on the national population register and comes to the same results shown in Figure 5 (Statistiek Vlaanderen).

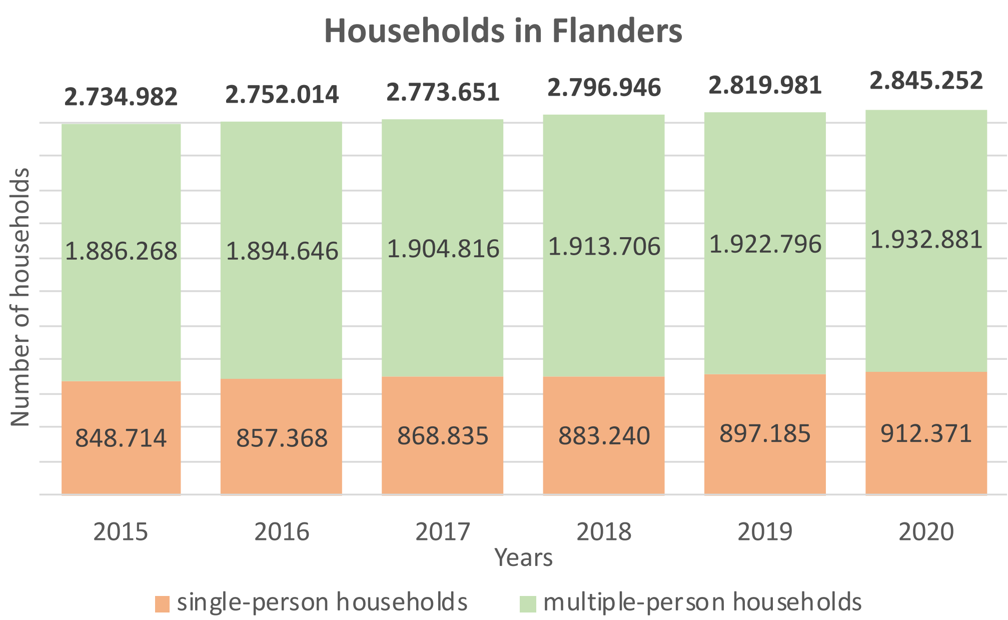

Figure 5: Number of single and multiple-person households, and the total number of households in Flanders by year [1].

Figure 5 depicts the numbers of single and multiple-person households. The number of households in Flandern is continuously rising. The six statistical groups of "married or unmarried couples with or without children living at home", "single-parent", "collective" and "other" household types are summarized under the multiple-person households category. Taking into account that 6.629.143 people were registered in Flanders by 2020 [2], on average 2,96 persons live in a multiple-person household. Moreover, the share of single-person households also slightly increased from 31,03% in 2015 to 32,07% in 2020. Thus, a growing demand on housing entities in Flanders can be observed, namely 110.270 more households over the last six years.

D2 Number of enterprises

Similar to the number of households indicator, the number of enterprises might provide an insight into the demand for office, production and retail space. Statbel provides the number of enterprises listed in the Belgium business register DBRIS and obliged to sales tax [3]. The data also includes the region of the companies' location, the employment size class, and the economic activity based on the NACEBEL 2008 nomenclature.

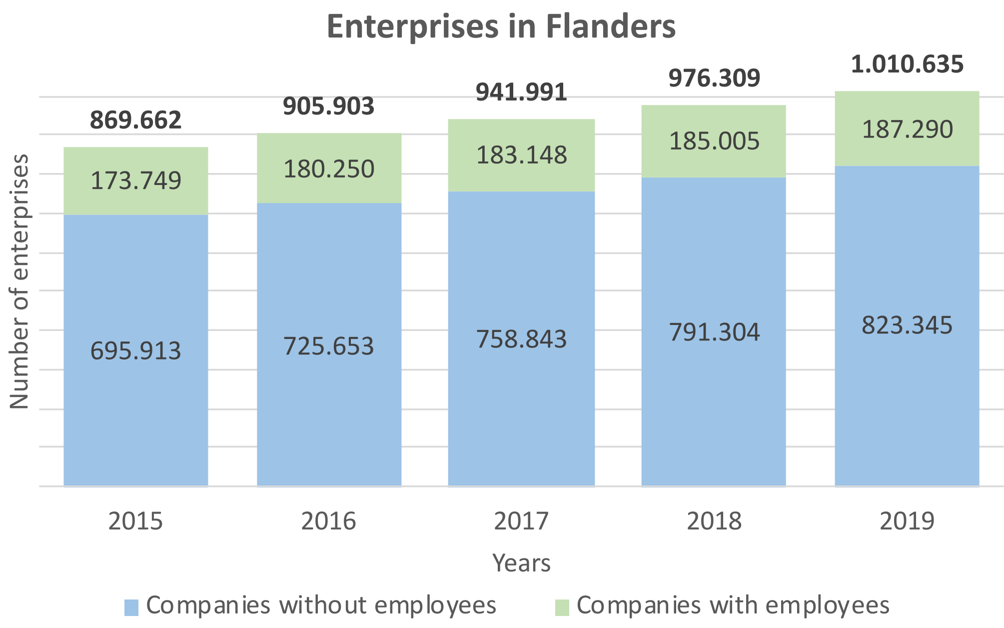

Figure 6: Number of companies with and without employees in Flanders by year [3].

As shown in Figure 6, the majority of companies in Flanders do not have any employees. This indicates a vast amount of one-man businesses, e.g. lawyers, or doctors having their own practice. These one-man businesses are less likely to demand additional real estate, as their services might be offered from the residential housing of the business owner. Enterprises with one or more employees probably need a co-working space, production site, storage, or retail shop. In either case, the numbers are constantly increasing in the last few years, which also implies an increasing need for commercial buildings.

D3 Total floor area of residential buildings

While the growing numbers of households and enterprises reflect the driving forces, the total floor area of residential, non-residential and all buildings are important indicators to measure the "size" of the need system. Government departments do not collect information about the built floor area directly, thus data cannot be provided to the public. Subsequently, the possibilities to approximate the indicator about the total floor area of residential buildings in Flanders was investigated.

Statbel's statistic "Gebouwenpark" provides the number of buildings categorized by region, building type, and the decade of the construction based on the information of the land register, called "Kadaster" [4]. From the TABULA project [5] the reference floor areas of the corresponding building and construction year classes can be taken and fitted with the categories and classes of the Gebouwenpark statistic. The sum of the number of buildings multiplied by the reference floor area results in the total floor area of residential buildings, as summarized in Figure 7. Although there are much fewer multi-family buildings than single-family homes in Flanders, they provide much more square meters of liveable space.

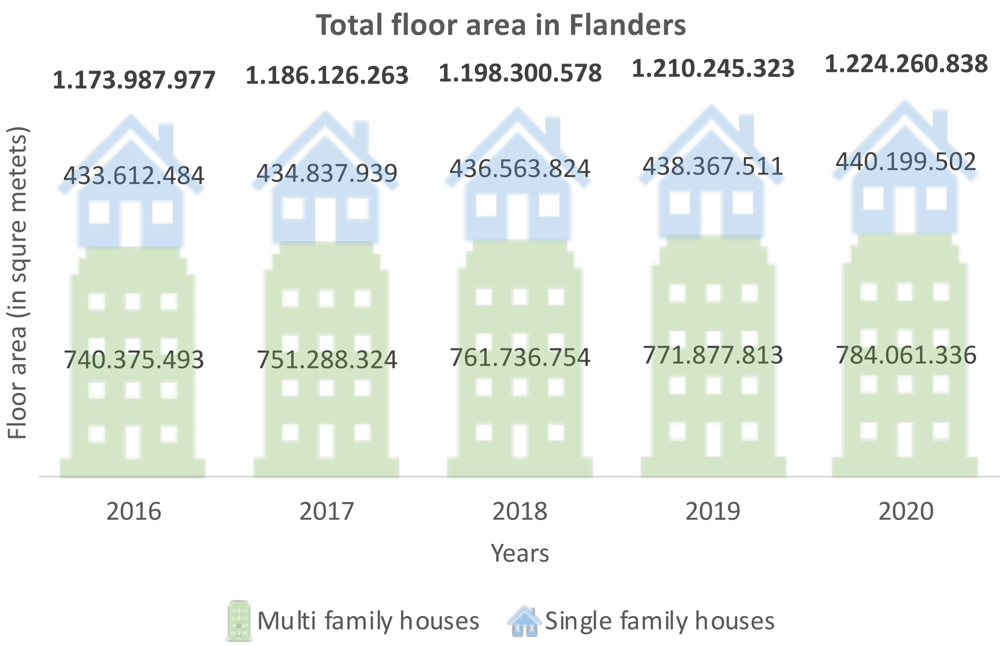

Figure 7: Total floor areas of multi and single-family houses, and all residential buildings in Flanders by year [4], [5].

D4 Total floor area of non-residential buildings

The category of non-residential buildings contains i.a. retail sites, offices, industrial buildings, schools, government buildings, shopping centers, or sport facilities. Thus, the building types are widespread over different industries, stakeholder groups, and facilitators, which makes information retrieval extremely difficult. Statbel differentiates in the Gebouwenpark statistics between the residential house types, commercial buildings, and "other" buildings [4]. However, there is no way to estimate the built floor area based on these numbers. Statbel indicates in the statistics about the yearly issued construction permits the total approved volume of the buildings. Again, these numbers do not allow conclusions to the built floor area, as heights and floor spacing between non-residential buildings vary vastly, and the issued construction permits just indicate new builds. So, the built stock of non-residential buildings cannot be approximated satisfactorily. Similarly, the land use of non-commercial buildings, as provided in some Statbel statistics, might indicate the size of the buildings' ground floors but does not let compute the built floor area, as the size and number of stories are unknown.

Interestingly, Cushman & Wakefield published the square meters of built stock of offices, logistics and semi-industry sites [6]. Of course, these numbers do not reflect the whole building stock of non-residential buildings, as e.g. the retail space, likely the biggest non-residential sector, is not numbered. Also, the office space is just collected for Antwerp, Ghent, Leuven, and Mechelen, thus does not represent whole Flanders. Further, open available numbers about public buildings, like schools, hospitals, or government offices, are missing for this indicator. Thus, the total floor area of non-residential buildings cannot be reported, computed, or approximated yet. Thus, Figure 8 only shows the data available so far and does not reflect the indicator results. As the floor area is a fundamental indicator, the results on behalf of non-residential buildings presented in the following sections of this monitor report will be limited.

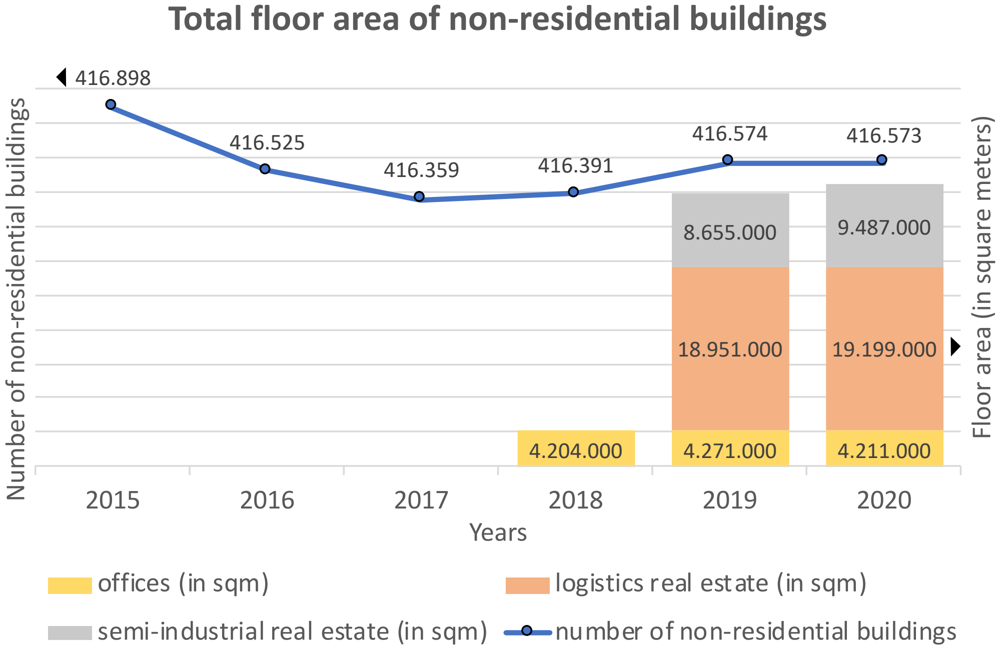

Figure 8: Total number of non-residential buildings and floor area of logistics, semi-industrial sites, and offices in Antwerp, Ghent, Leuven, and Mechelen [4], [6]. However, exact numbers on non-residential building floor areas are missing and the indicator D4 cannot be computed yet.

D5 Total floor area of all buildings

The total floor area of all buildings depends on the results of the total floor area of residential (D3) and non-residential (D4) buildings. Consequently, also this indicator cannot be provided yet, due to the data gap about non-residential buildings as described before.

P1 Tons of virgin raw materials, fuels and water excavated for buildings and housing

Observing this need system, buildings have to be seen as a product fulfilling the need. In this context, buildings are a quite complex product. Depending on their practical task, i.a. providing living, office, retail, or industrial space, they consist out of different materials, their dimensions vary enormously, and their product lifetimes normally stretch over decades. The indicator P1 focuses on the raw materials, fuels, and water excavated for erecting and using a building, e.g. through renovating, heating, and lighting. Thus, this indicator represents the material footprint of the building fulfillment system. Although the total material consumption of the buildings would be the optimum to measure, such data is not collected or available yet, as reported by (Christis & Vercalsteren, 2020).

Christis et al. (2021) computed **28.387 kton** of material footprint for household consumption on housing, as shown in Figure 2. This number just describes the material footprint from the private consumption perspective. It relies on the EORA input-output database, and VITO's input-output models specifically for Flanders to convert economic consumption figures from Euros to tons of materials and emissions. Thus, non-household consumption was not allocated to the consumption domains yet. As material flows within a country are not recorded by public bodies up to now, the allocation of macro consumption numbers (e.g. PRODCOM or COICOP data) to the different need systems is problematic. So, a bottom-up approach was attempted to deliver a result for the material footprint of the entire building and housing need system.

Material footprint of erecting buildings

So far, the material footprint of economic sectors was computed based on economic figures, such as revenues. In this study, an allocation of nationwide numbers based on a bottom-up approach was attempted. In this regard, a model of the composition of a building is important. Following the demonstration example in Figure 9, the building shell consists out of several elements, such as walls, roofs, doors, and windows. Every element needs construction materials, e.g. concrete, bricks, steel beams, aluminum frames, or window glass. These construction materials are made out of fairly known materials, like cement, stones, loam, steel, aluminum or copper alloys, which again are obtained out of raw materials and minerals. Hence, the excavated raw materials are the central information of this indicator.

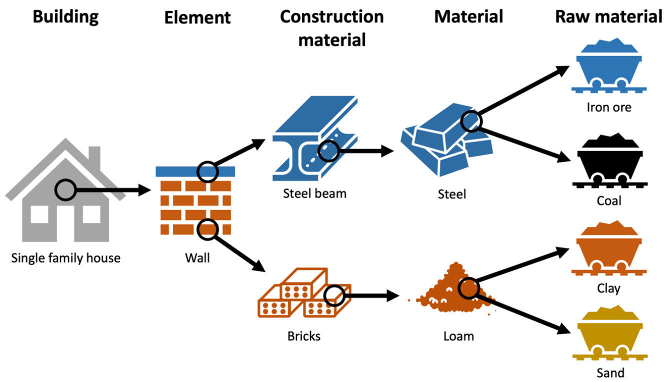

Figure 9: Demonstration example of the composition of a building.

For their urban mining model, Metabolic's team investigated the material needs and composition of twelve residential and non-residential building types when newly built in the Netherlands (Arnoldussen et al., 2020). Figure 12 and Figure 13 show the study's results for the residential and non-residential buildings, respectively. The figures illustrate that concrete is by far the most important construction material, followed by wood, bricks, and steel measured by weight.

In the statistics about the issued building permits by year, Statbel also publishes the total floor surface approved to be constructed [8]. Based on the permitted floor area and Metabolic's material need numbers, the material demand for constructing new residential buildings can be approximated. For this approximation, the following assumptions were made:

- Architects and construction companies in Belgium and the Netherlands plan and build similarly, thus the dutch buildings' compositions are a useful proxy for Belgium too.
- As the most common type, the detached single-family houses composition was used to represent the median of all single-family house types.
- The buildings were permitted, erected, and finished within the same calendar year.

The permitted floor areas were classified either as single or multi-family buildings based on the reference floor area in the TABULA Webtool, explained earlier. Then the specific material needs and compositions of detached single-family houses and apartment blocks were used to estimate the material demand for erecting residential buildings. Figure 10 shows the total material demand derived from the floor area stated in the construction permits. The model of this study only allows deviation of the material demand from the permits' floor area with changing shares of single and multi-family houses in different years. However, a change because of new building materials or techniques cannot be traced yet, due to missing data. Because single-family houses require a different ratio of the materials as multi-family buildings in this model, Figure 11 exhibits slight ratio shifts in the material categories within a year, depending on the share of single-family houses among the issued permissions.

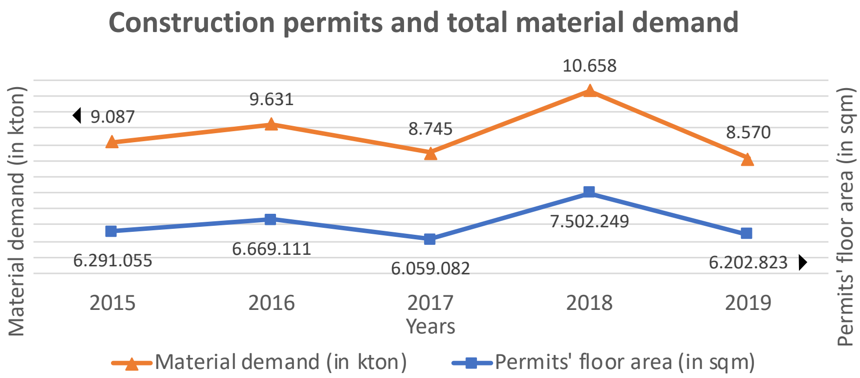

Figure 10: The floor area (in m^2) stated in construction permissions in Flanders and the thereof derived material demand (in kton).

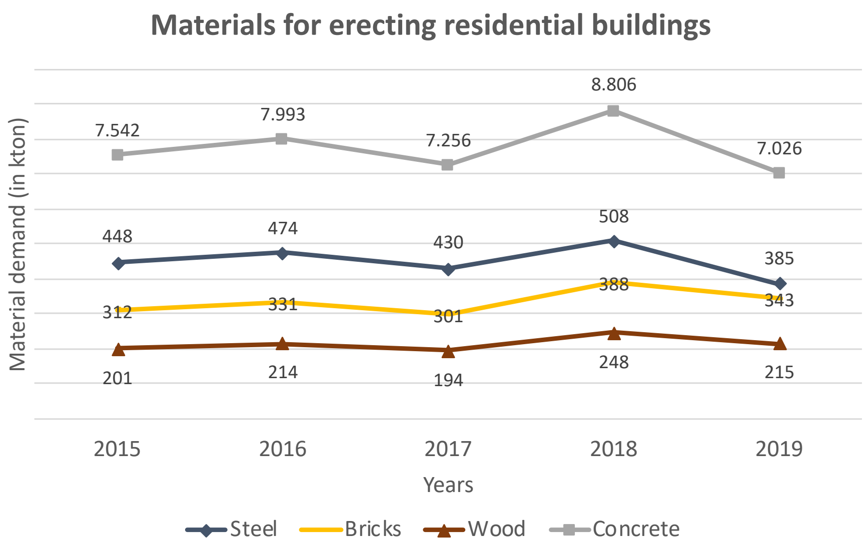

Figure 11: The material demand of the four most important materials to erect residential buildings in Flanders.

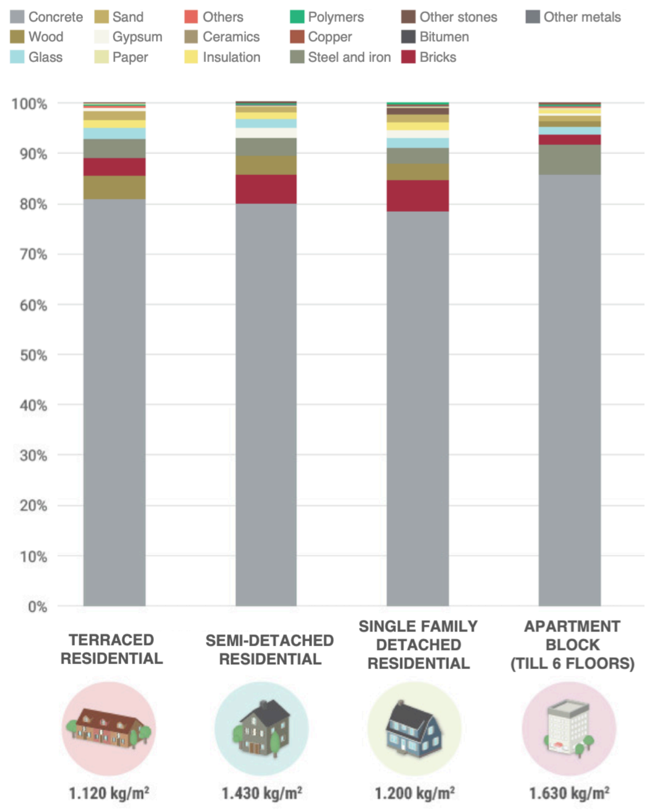

Figure 12: Materials needed for new constructions of residential buildings; the result of a study by Metabolic and SGS Search [7].

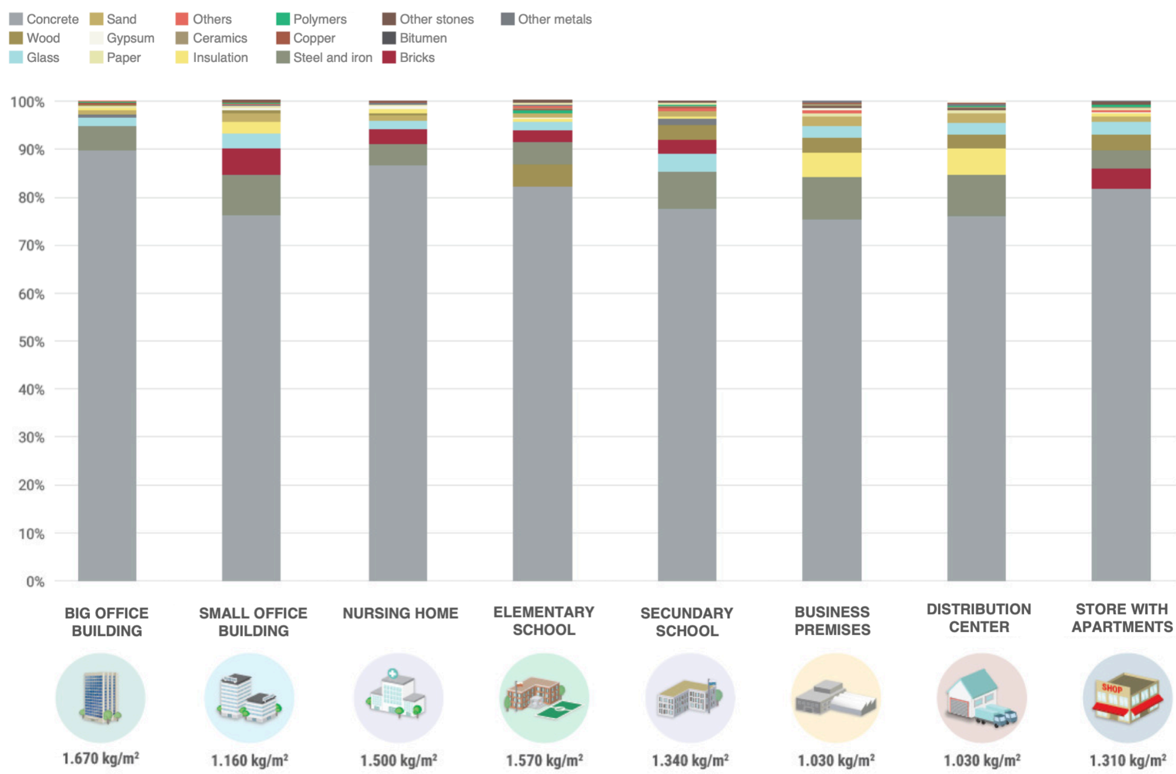

Figure 13: Materials needed for new construction of non-residential buildings; the result of a study by Metabolic and SGS Search [7].

The information in Figure 11 was used to model the needed raw materials for residential buildings. In the GaBi LCA software, the four aggregated processes of Thinkstep

- EU-28: Concrete C20/25 (Ready-mix concrete) (EN15804 A1-A3) ts [9],
- EU: Steel rebar worldsteel [10],
- EU-28: Bricks vertically perforated (EN15804 A1-A3) ts [11], and
- EU-28: Solid construction timber (softwood) (EN15804 A1-A3) ts [12]

were chosen to represent the four material streams from cradle to gate. Of course, this step is yet another simplification and just gives an insight into a fraction of the complete supply chain of residential buildings. Amongst others, materials like polymer, copper, bitumen, insulation, paper, ceramics, or glass, and transportation and fuel needs at the buildings' construction site were not investigated. Figure 14 summarizes the resources needed to erect the residential building in 2019. Thus, the material footprint was even higher in the years before than in 2019.

Resource	Amount
Energy	469.734.757 MJ
Water	638.650.696 t
Natural Aggregate (gravel)	5.776.975 t
Inert rock	2.935.758 t
Soil	1.141.241 t
Limestone (calcium carbonate)	971.717 t
Clay	370.419 t
Iron (Element)	291.226 t
Dolomite	54.547 t
Gypsum (natural gypsum)	22.802 t
Quartz sand (silica sand; silicon dioxide)	9.981 t
Shale	5.921 t
Bauxite	3.079 t
Manganese (Element)	2.147 t
Potashsalt, crude (hard salt, 10% K2O)	1.464 t
Bentonite	1.122 t

Figure 14: Most needed resources for concrete, bricks, steel, and wood erecting the residential buildings in 2019.

As discussed earlier, the total floor area of non-residential buildings in Flanders is not available. Hence, a different approach had to be taken to approximate the material footprint of non-residential buildings erected in 2019. Statbel provides not just the number of permitted non-residential buildings, but also the buildings' volume [8], as shown in Figure 15.

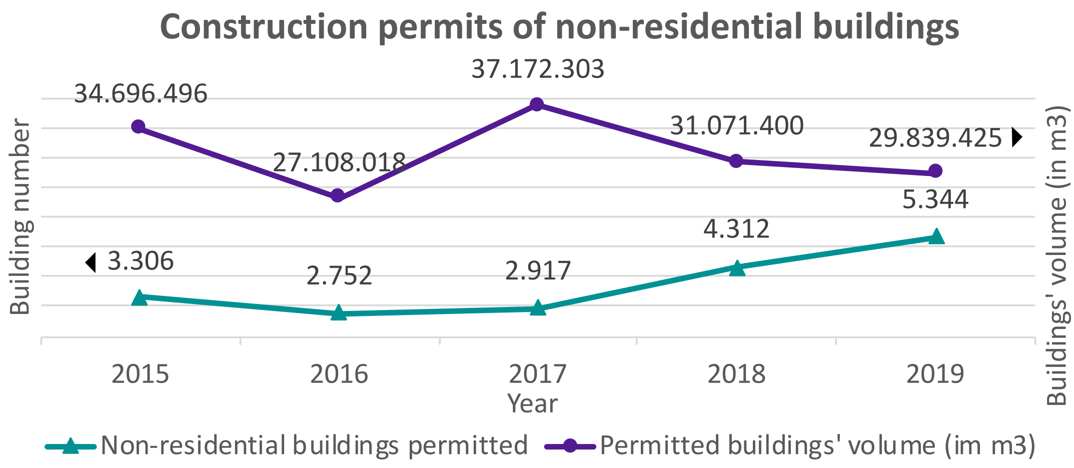

Figure 15: Number of non-residential buildings permitted and their volume [8].

The values of the buildings' volume permitted in 2019 can be feed into an aggregated process in the GaBi software to model the resource needs and emission caused. Ecoinvent offers the process "RER: building construction, multi-story" [13]. The input and output values in the process were obtained from two concrete buildings built in 1927 and 1972. Thus, the obtained results in Figure 16 estimate the number of resources poorly, as neither different non-residential building types, regional flemish data, nor shifts due to advancements in the construction sector are taken into account. This non-residential building model includes all in the Ecoinvent process given information about materials, their production and building construction step, in contrast to the residential building model, focusing on the four most important materials. However, as the model is fundamentally different from the residential building approach, comparisons between the two intermediate results are not convincing.

Resource	Amount
Energy	5.413.213.168 MJ
Water	59.258.993.715 t
Gravel	9.690.415 t
Clay	7.324.478 t
Inert rock	3.222.567 t
Calcite, in ground	1.626.895 t
Aluminium (Element)	303.426 t
Iron (Element)	301.677 t
Copper (Element)	178.436 t
Sodium chloride (rock salt)	67.890 t
Gypsum (natural gypsum)	36.202 t
Shale	34.747 t
Basalt	28.587 t
Dolomite	4.237 t
Bentonite clay	3.610 t

Figure 16: Most needed resources for concrete, bricks, steel, and wood erecting the non-residential buildings in 2019.

In summary, at least 5,88 PJ of Energy, 59.897 million kton of water, 15.467 kton of gravel, and 7.695 kton of clay can be allocated to the construction of residential and non-residential buildings in Flanders 2019. In total, **34.746 kton** of non-renewable raw materials and fuels were needed. The Excel file in the annex of this report shows more detailed results of the computation of the computed material footprint. However, several of these resources might be excavated abroad and imported as raw material equivalents of the construction material.

Material footprint of heating buildings

Heating buildings is one of the biggest energy consumption domains and emission sources. So, this topic is a focus of research for several years already. Accordingly, significant data about the material footprint of heating buildings is publicly available. Figure 18 shows the results of a study of VMM and VITO, summarizing the households by their heating energy source and their computed consumption (de Bruyn et al., 2019). The challenge thereby is the allocation of electricity as a heating source. Of course, electricity might be used for several things, but VMM computed the number of households heating with electricity in 2015. This is important information not provided in the Flemish Energy Balance of VEKA [14].

Contrarily, the material footprint of heating of non-residential buildings is more difficult to estimate. In their Flemish Energy Balance, VEKA indicates the energy consumption of the ternary sector, retail and administration buildings. It is reasonable to assume that the majority of this energy consumption is used for building heating, as these service-oriented businesses generally have no interest in adding or converting the energy into different products. However, the industry sector has a significant demand for energy carriers for machines, production processes, and assembly lines. Thus, data about the allocation of the energy consumption of the primary and secondary economy sectors to building heating is not available yet and might require company-specific data. In 2015, Flemish households and the ternary sector used **466 PJ** for heating, beside an unknown amount of the primary and secondary sectors. Based on the use of the energy carriers, a material footprint of **8.809 kton** for heating can be approximated.

Heating sources	Number of households	Energy consumption 2015 (PJ)
Natural gas	1.825.308	85,1
Fuel oil	754.179	57,7
Propane, Butane, LPG	29.200	2,1
Coal	29.200	1,5
Wood (main source)	45.434	1,8
Wood (additional source)	558.998	10,8
Electricity	236.724	4,5
Total	**2.920.045**	**164**

Figure 17: Number of households by heating source and the corresponding heating energy consumption in 2015 (de Bruyn et al., 2019).

Heating sources	Energy consumption 2015 (PJ)	Energy consumption 2016 (PJ)	Energy consumption 2017 (PJ)	Energy consumption 2018 (PJ)	Energy consumption 2019 (PJ)
Natural gas	131,9	140,2	138,1	139,1	138,4
Fuel oil	63,9	63,5	63,3	61,9	59,8
Propane, Butane, LPG	2,6	2,8	2,5	2,5	2,5
Coal	1,0	0,3	0,2	0,2	0,3
Biomass	16,2	17,9	16,8	16,7	16,7
Total	**302,6**	**311,7**	**308,6**	**308,4**	**305,2**

Figure 18: Heating energy consumption of the ternary sector, retail, and administration [14].

In summary, the material footprint accumulates to **43.554 kton** of non-renewable raw materials and fuels for heating (2015), materials production, and buildings construction (2019).

P2 Emissions emitted for buildings and housing

Despite the production of building materials and the use of buildings causes several different emissions to air and soil, this study only focuses on CO_2 and $PM_{2,5}$ emission as a start, due to data availability. As the material footprint, the carbon footprint of **22.077 kton CO_2eq** (Figure 2), reported by Christis et al. (2021), just considers private consumption on housing. Thus, the results of the GaBi LCA software model, described before, were taken to deliver a result for the building and housing need system. Also, this indicator has two major contributions: the production and building construction phase and the use phase, primarily due to heating.

Impacts	Residential buildings	Non-residential buildings	Totals
Global Warming Potential incl. biogenic CO_2 (in t CO_2eq)	1,28 million	7,07 million	**8,36 million**
Global Warming Potential excl. biogenic CO_2 (in t CO_2eq)	1,66 million	9,59 million	**11,2 million**
Particular Matter Emissions (in t $PM_{2,5}$eq)	570	16.600	**17.170**
Resource Depletion Water (in m^3eq)	10,2 million	61,3 million	**71,5 million**

Figure 19: Emissions modeled with the GaBi software to estimate the impact of production and building construction.

For the production and construction phase, immediate measurements of emissions are challenging to conduct, so direct data does not exist. The two models for residential and non-residential buildings in the GaBi software, described in the previous section, were used to estimate the emissions caused, thus providing a proxy for this share of the indicator. Figure 19 lists the results obtained for the global warming potential, particular matter emissions, and water resources depletion. A direct comparison between the values of residential and non-residential buildings is not valid, as the numbers were computed by fundamentally different models. Like the corresponding material footprint, the emissions might have been caused at the mining site of the raw materials or the production site of the construction material, thus not necessarily directly in Flanders. It is estimated that housing accounts for 22.077 kton CO_2eq (Figure 2). Additionally, another 7.000 kton CO_2eq caused by non-residential buildings (Figure

19) should be added resulting in a share of 29,5 % of the flemish carbon footprint in 2016 (as shown in Figure 2).

VMM measures air pollution categorized by different sectors. Two of these sectors are heating of household buildings and retail and service buildings [15], [16]. Just as the material footprint, the allocation of emissions due to heating of industrial buildings, and not due to their production, is subject to further research. Based on the measured emissions of VMM, the $PM_{2,5}$ and CO_2 equivalents were calculated and depicted in Figure 20. Especially the $PM_{2,5}$ emissions highly depend on the heating energy form. Wood, as the main or additional heating source for more than 600.000 households, is the most significant contributor to the enormous share of residential buildings in particular matter emissions, as many households do not have filters applied in the exhaust streams. (VMM, 2018).

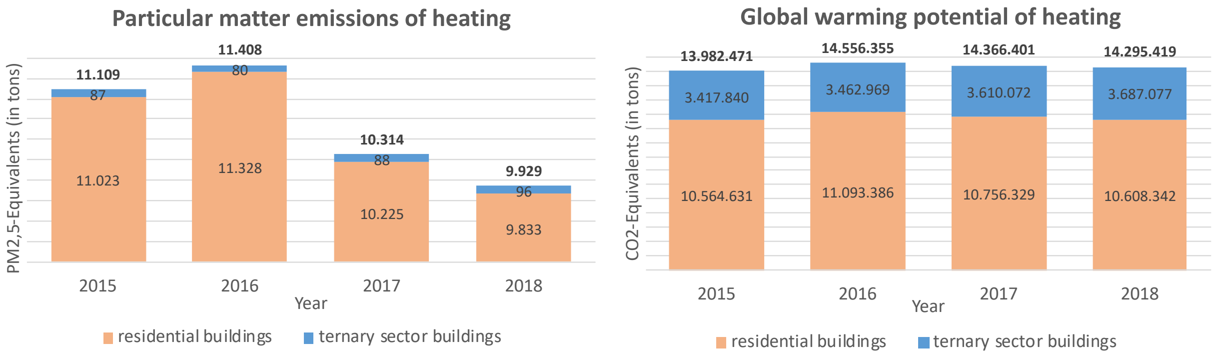

Figure 20: $PM_{2,5}$-Equivalents and global warming potential caused by heating computed based on the measured emission data by VMM [15], [16].

The number of emissions computed based on the number for material production and building constructions in 2019 and on the latest figures about heating households and ternary sector buildings in 2018 sum up to **27.099 t $PM_{2,5}$eq** and **22.655 kton CO_2eq**. In reality, these impacts are higher, as several material groups for residential buildings, heating of primary and secondary economy sector buildings, repairs, renovations, real estate services, and waste treatment were not included in this study.

P3, S3 Area of built surface, Area of natural land

Erecting a building means occupying a certain amount of land for a long time if not permanently. Not just the excavation for the construction material but also the land use is severe pressure on the environment and biodiversity. The increasing degree of paved surfaces causes significant interference in the global carbon cycle and the natural water cycle. Thus, the pressure of the built surface as well as the current state, namely the area of natural land, are important from a Circular Economy perspective on the building need system.

Mostly based on the land register, Statbel also provides numbers on the land use in Flanders [17]. Therein, a notable surface area has no use indication. Because of the data provided by the parcels in the land register, it is reasonable to expect that this surface area is unused, thus natural land [18]. Figure 21 shows that the pavement degree of Flanders, which is already densely populated, keeps growing. The figure underlines that areas for residential houses and transportation and communication infrastructure are by far the biggest portion concerning built surfaces, while the category “Others” summarizes spaces for mixed-use, pits, mines, recreation and technical facilities. In 2019, residential, industrial, commercial and public buildings occupied 231.587 ha**, a constantly increasing number bigger than the entire region of Vlaams-Brabant. On the other hand, the area of **natural land** amounted to **974.807 ha**, mostly used for agriculture. Thus, 28,5 % of Flanders' 1.362.555 ha is built surface, mostly used for building, transportation and communication needs.

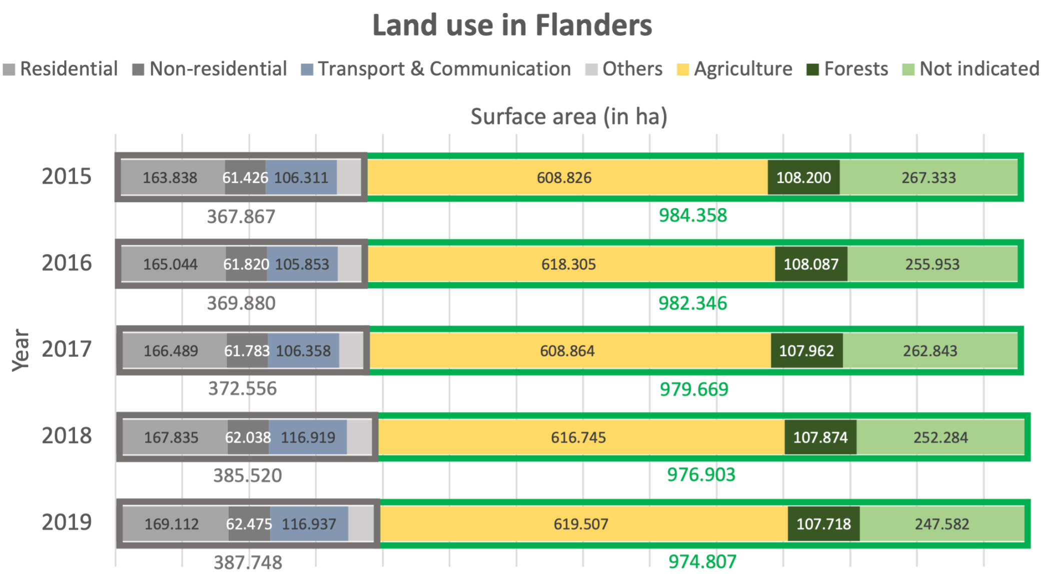

Figure 21: Surface area occupied by forests, agriculture, residential, non-residential and transportation & communication buildings [17].

S1 Tons of virgin raw materials, fuels and water reserves

While resources are measured deposits of commodities, reserves are proven deposits, which can be mined economically. This indicator focuses on the number of commodities in economically significant mineral deposits in Flanders. Figure 22 shows the reported reserves of the important minerals for the building fulfillment system. Notably, Flanders neither has any reserves of coal, crude oil, or natural gas, which are important fuels for heating and electricity, nor iron ore, which is important for the steel construction of buildings. The numbers for clay might also include marlstone, which is crucial for cement production. Open available numbers on gravel, limestone or calcite reserves in Flanders were not found, probably because they are very widespread resources with high availability and amounts. The densities for loam, clay, and sand might vary between 1,8-2,2 t/m^3, 1,3-2,0 t/m^3, and 1,2-1,6 t/m^3, respectively. Thus, the reserves listed in Figure 22 roughly translate into 18.600 kton of loam, 24.200 kton of clay, and 911.900 kton of sand in Flanders. As the data is quite outdated, already new pits at new reserve locations might have emerged to fulfill the production demands.

Commodity	Amount	Report publisher	Report year
Loam (red)	3.974.623 m^3	LNE	2008
Loam (yellow)	5.327.190 m^3	LNE	2008
Clay (various)	14.680.085 m^3	LNE	2004, 2008
Sand onshore	3.671.860 m^3	LNE	2004, 2008
Sand in the Belgian part of the North Sea	647.740.000 m^3	SPF Economie	2017

Figure 22: Overview of the reserves of raw materials important for constuction materials [19], [20], [21], [22], [23].

In general, Flanders is a region with high water stress. VMM reported that 1.150 m^3 per person is available in Brussels and Flanders (Peeters, 2013). The water availability takes into account the average annual precipitation surplus (precipitation minus evaporation), the flow rate entering via rivers, and the inflow of ground and surface water. This would correspond to approximately **8.666.968.100 m^3** of annual **water reserves** for Brussels and Flanders. It represents the total amount of water useable for industry, production lines, private households, and agriculture in Flanders every year.

S2 Emissions concentration (Air quality)

As one of the major greenhouse gases, the atmospheric CO_2 concentration is measured constantly at the Mauna Loa Observatory in Hawaii (Figure 23). The residence time in the atmosphere is also sufficiently long to globally achieve homogeneous mixing. As a result, the precise location of emissions does not matter, thus, the CO_2 concentration in Flanders equals the one in Hawaii. Of all the carbon dioxide emitted by human activities, about half remains in the atmosphere. In 2016, the annual mean atmospheric concentration of CO_2 exceeded the threshold of 400 ppm. At 415 ppm, the concentration is now 49 % above the preindustrial level of 278 ppm. The current rate at which the atmospheric concentration of CO_2 is increasing has never been higher in the past twenty years (Brouwers et al., 2018).

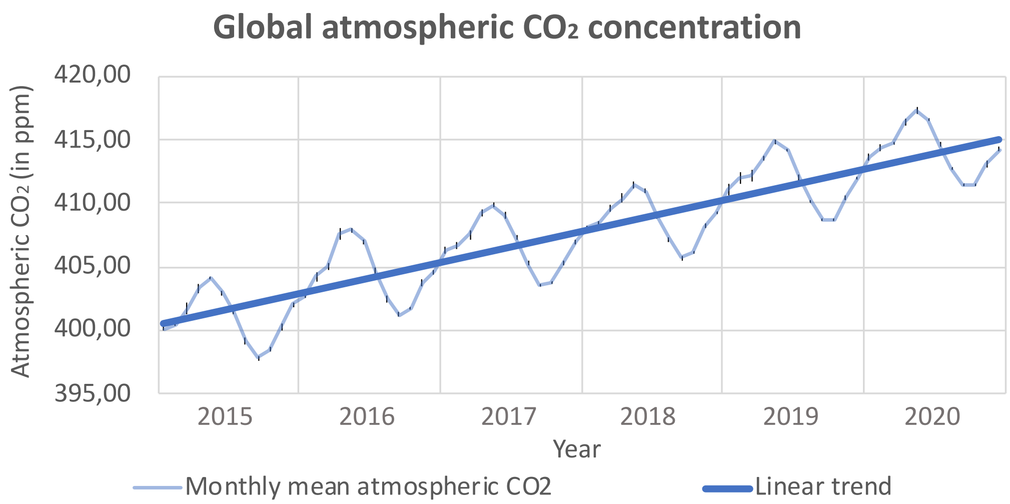

Figure 23: Monthly mean CO_2 constructed from daily mean values measured at Mauna Loa Observatory, Hawaii [24].

On the other hand, the location of particular matter emissions is important for the affected people. Therefore, the European Union (EU) and World Health Organization (WHO) set limits for the PM_{10} and $PM_{2,5}$ concentrations. The limits of the two bodies are summarized in Figure 24. While the EU takes economic consequences and technical feasibility into account for the limitations, the WHO purely reasons the limits with human health protection (VMM, 2018).

Limits	EU	WHO
Maximum annual PM_{10}-concentration	40 µg/m^3	20 µg/m^3
Maximum annual $PM_{2,5}$-concentration	25 µg/m^3	10 µg/m^3
Maximum days with high PM-concentrations	35 days	3 days

Figure 24: Limits of the EU and WHO about particular matter (PM) emissions (VMM, 2018).

In 2017, all 36 PM_{10} and 37 $PM_{2,5}$ measuring stations in Flanders met the European targets on an annual and daily basis. On the other hand, only five PM_{10} stations met the annual WHO PM limits, while no station, neither PM_{10} nor $PM_{2,5}$, met their daily targets. According to the National Air Pollution Control Programme, Flanders emitted 12,5 kton of $PM_{2,5}$ emissions in 2017. In the same year, heating of residential and ternary sector buildings accounted for 10,3 kton of $PM_{2,5}$ emissions (Federale Regering, 2019). Thus, heating contributes at least 82 % of PM emissions in Flanders every year; PM emissions caused by the domestic construction material production and building erection have to be added on top of that in the context of the building need fulfillment system.

I1 Number of homeless people

The need system for buildings also has impacts on nature, and humans. As one of the essential needs, it is crucial to every society. Homelessness is one of these important social-economic impacts. The reasons for homelessness might be manifold, however building stock, or real estate market size, and the real estate p+rices, consequentially, are several of the main contributors for people facing homelessness. Unfortunately, there is no official, government data about homelessness in Flanders or Belgium. A study of the Steunpunt Welzijn, Volksgezondheid en Gezin numbered 711 adults and 51 children in winter shelters, thus totally unsheltered, and 3.019 adults and 1.675 children registered at the homeless service in the period between 15 January and 15 February 2014. So, 5.456 people were known to face homelessness by February 2014. Additionally, 599 people were threatened with evictions in the same period in Flanders (Meys, 2014). Without governmental data or official statistics, no conclusion about the development of homelessness can be made.

I2 Number of people affected by emissions

It is fairly known that CO_2 drives global warming and, thus, affects every human and nature. In contracts, particular matter emissions affect the local population and their respiration organs. Based on the limits of the EU and WHO, explained in Figure 24, and the results of the measuring station in Flanders, VMM also calculates the share of the population in Flanders affected by PM emissions. Notably, no safe threshold value exists below which no harmful effects occur according to the WHO (VMM, 2018).

Emissions	Limit	EU	WHO
PM_{10}	annual	< 652 (< 0,01%)	1.303.202 (20%)
	daily	< 652 (< 0,01%)	6.255.371 (96%)
$PM_{2,5}$	annual	0 (0%)	6.190.210 (95%)
	daily	n.a.	6.516.011 (100%)

Figure 25: Number and share of the population affected by particular matter (PM) emissions in Flanders 2017, according to the corresponding EU and WHO limits (VMM, 2018).

Figure 25 shows that, according to the EU, only a small portion of the Flemish population was affected by the particular matter emissions in 2017. The more stringent limits of the WHO imply that the majority faced or will face aftermaths of PM pollution. As highlighted in the section of the emissions concentration indicator (S2), only building heating contributes roughly 82 % of the PM emissions in Flanders. Thus, the building need fulfillment system is the biggest PM emitter.

I3 Number of people facing water scarcity

The World Data Lab, supported by the German BMZ, the GIZ GmbH and, the IIASA, provide a webpage called "Water Scarcity Clock" [25]. The project computes the population of every country facing water scarcity. Therefor, they indicate three categories:

- Absolute water scarcity: regions with an average annual water availability of fewer than 500 m^3 per person
- Water scarcity: regions with an average annual water availability of 500-1000 m^3 per person
- Water stress: regions with an average annual water availability of 1000-1700 m^3 per person

Figure 26 summarizes the population facing water stress and scarcity in Belgium. The Water Scarcity Clock models that nobody in Belgium should encounter absolute water scarcity. However, its predictions for 2030 suggest a remarkable increase of people affected by water scarcity. Also, the geographic representation of the data allocates the majority of the affected people in the Flemish region. Especially the building fulfillment system is expected to have a significant contribution to this impact category. Another 1.714 ha of land was sealed by new buildings (Figure 21), which represents 77 % of the built land expansion in 2019. This results in 71,5 million m^3eq of water depletion (Figure 19) caused by the production of materials and the construction of new buildings, while Flanders and Brussels faced 8.667 million m^3 of water reserves (S1). Along with the assignable greenhouse gas emissions, the facts mark a serious interference in the natural water cycle, and, thus, a major contributor to the predicted increase in water scarcity.

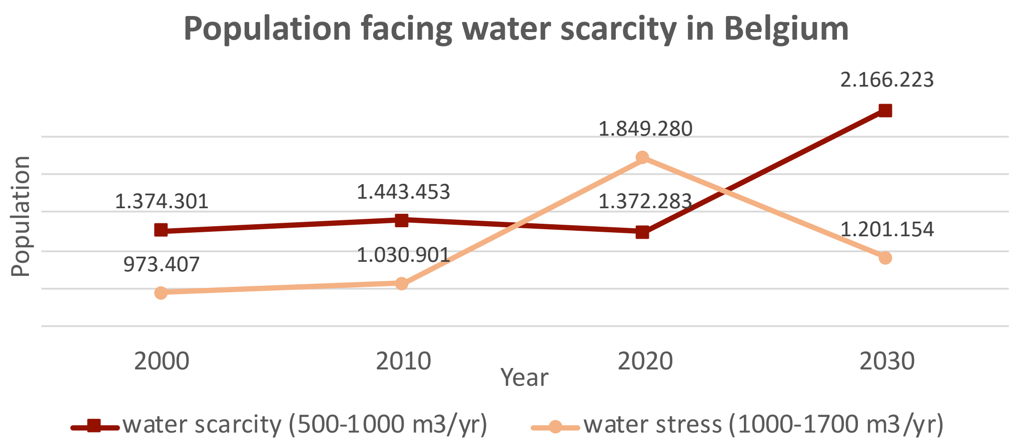

Figure 26: Population facing water stress and scarcity in Belgium [25].

R1 Raw materials efficiency

Response indicators should measure policies and their effectiveness. One important task is to decouple the material and carbon footprint from economic growth. This might be achieved by increasing efficiencies. In the context of the building need system, the tons of raw materials used per floor area of building, thus the raw material efficiency, is of interest. The indicator can be computed by dividing the material footprint (P1) by the floor area constructed in the same year. However, in this study, the material footprint was partly derived from data about the permitted floor area and the materials need highly depend on the specific weight presented in Metabolic's study [7]. So, the material footprint is not independent of the floor area and, on the other hand, information about the floor area of non-residential buildings is not available. Thus, a proxy of this indicator cannot be computed in this study.

R2 Surface use efficiency

Surface use efficiency measures how much useable floor area a building provides while occupying a certain amount of surface space. Thus, surface use efficiency increases, e.g., with the number of floors in a building. The surface efficiency is important to reduce the pressure on natural land. This might be achieved also by the densification of already built areas. Based on the surface areas of the parcel types in the land register provided by Statbel [18], the surface efficiencies of single and multi-family houses were computed. Also, based on the numbers of the built land (P3) and the total floor area of residential buildings (D3), the average surface efficiency was computed.

Figure 27 indicates that the surface efficiency of single-family houses and residential buildings, in general, were quite constant, while the efficiency of multi-family homes was decreasing. Yet, multi-family houses provide on average 32 times more livable space than single-family houses on the same area of land. While apartment buildings offered **8,4 m²**, single-family houses just had **0,26 m²** of floor area per square meter of the land surface. The difference between the efficiencies is partially enormous because the land register also includes the garden surrounding the single-family home within the same land parcel. Nevertheless, even a two-story-high single-family house would never exceed 2 m^2 of floor area per square meter of land. However, also extreme building heights might cause bigger environmental impacts than average apartment blocks, despite better surface use efficiency. Taller buildings require deeper foundation works causing an impact to the surface soil and ground water system.

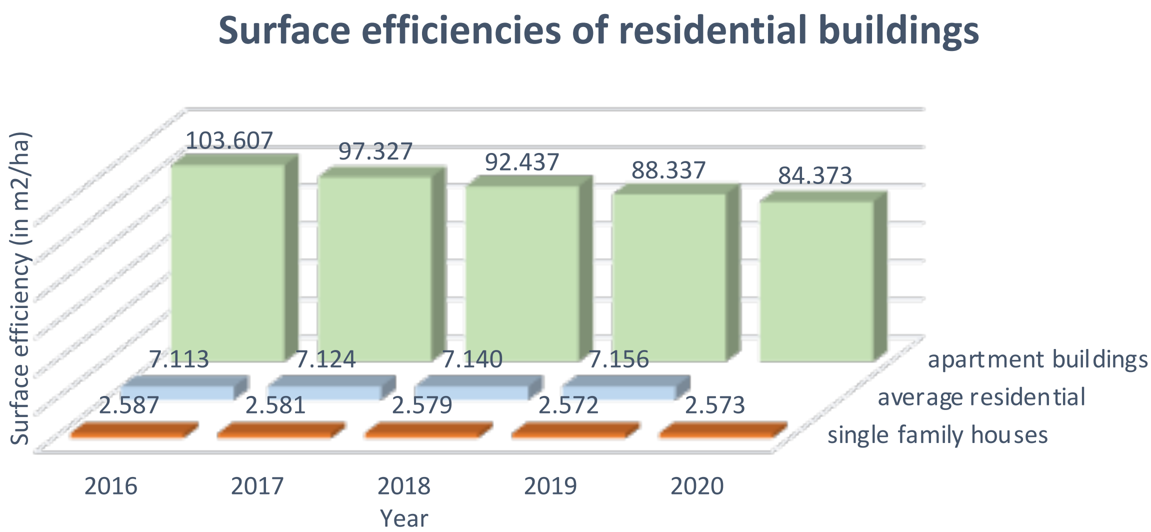

Figure 27: Surface efficiencies of single and multi-family houses, and residential buildings on average [17], [18].

R3 Use efficiency (Occupancy rate)

Between 2010 and 2016, the Flemish municipalities had to use the "leegstandsregister", a platform where each town could input their data about unoccupied real estate. However, this is not obligatory anymore since 2016. Towns were given the autonomy to define their own requirements and methods for registration about vacancies. Consequently, no actual or complete data about unoccupied real estate in Flanders is available. So, a proxy was computed out of the annual number of households (D1) and the number of housing units indicated in Statbel's "Gebouwenpark" statistics [4].

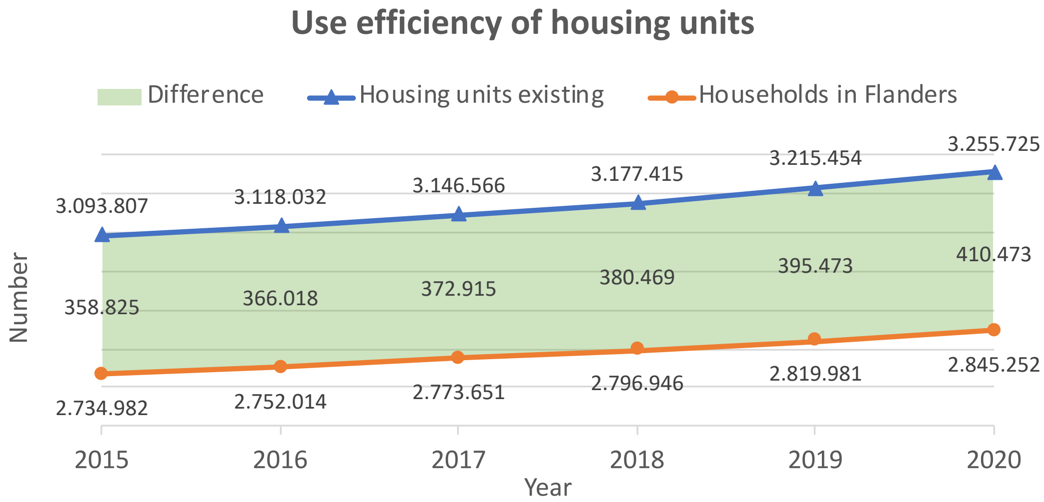

Figure 28: Number of households and housing units in Flanders [1], [4].

Figure 28 might indicate around 12 % of vacant dwellings, but this also includes holiday houses, which usually sit along the coastline and are just secondary residences for families. The number of heated dwellings, presented in Figure 17, is a good approximation of how many units are actually in use. Thus, the 2.920.045 heated housing units suggest that only 173.762 housing units were vacant, and thus unheated, in 2015. This is more or less 48 % of the difference shown in Figure 28. So, it is reasonable to assume that approximately **205.000 units**, or **6,3 %**, were unoccupied in 2020.

Parallel to the data for the indicator about the total floor area of non-residential buildings (D4), also information about the vacancy rates is rare. Cushman & Wakefield publishes vacancy rates of offices, but only in Antwerp and Ghent (Figure 29), and they do not provide vacancy rates of logistics or semi-industrial real estate.

Vacant offices	2019	2020
Antwerp	6,46 %	10,01 %
Ghent	4,85 %	3,97 %

Figure 29: Vacant offices reported by the end of the year [6].

R4 Heating efficiency

Heating efficiency helps to reduce the pressure caused in the use phase of a building. An increased heating efficiency ultimately reduces the volume of fuels mined for heating. The heating efficiency highly depends on the materials and insulation techniques used when the building was constructed. Due to regulations, every dwelling needs to have an Energy Performance Certificate (EPC) when sold or rented out. The certificate is issued after thermal conduction measurements and states the need for annual heating energy in kWh/m^2 of the property. The actual heating source, e.g. natural gas, electricity, wood, is not a factor for the EPC score. Also, the EPC is obligatory only for residential units to date. Thus, data about commercial or industrial buildings do not exist yet. Figure 30 shows that 932.246 housing units already had an Energy Performance Certificate in 2016. Their average EPC scores for apartments, multi-family buildings, and single-family homes vary remarkably with **293 kWh/m²**, **386 kWh/m²**, and **489 kWh/m²**, respectively. Figure 31 underlines the influence of building type and construction year on the annual heating energy consumption of housing.

	Apartment		**Multi-family building**		**Single-family home**	
	Amount	EPC	Amount	EPC	Amount	EPC
A: <=1920	***16052***	***373***	***793***	***405***	***41850***	***549***
B: 1921-1945	***17252***	***380***	***607***	***421***	***61455***	***541***
C: 1946-1970	***94671***	***343***	***939***	***394***	***155227***	***549***
D: 1971-1985	***65915***	***273***	***215***	***332***	***71023***	***418***
E: 1986-1995	***45787***	***246***	***176***	***260***	***35221***	***330***
F: 1996-2005	***57622***	***195***	***141***	***235***	***32573***	***236***
G: >2005	***26331***	***153***	***95***	***193***	***7799***	***186***
H: unknown	***73036***	***365***	***1433***	***407***	***126033***	***538***
Totals	**396666**	**293**	**4399**	**386**	**531181**	**489**

Figure 30: Average EPC scores of residential buildings, included in the Energy Performance Certificate database in 2016, according to the construction year (A-H) and building type (Vlaamse Overheid, 2017).

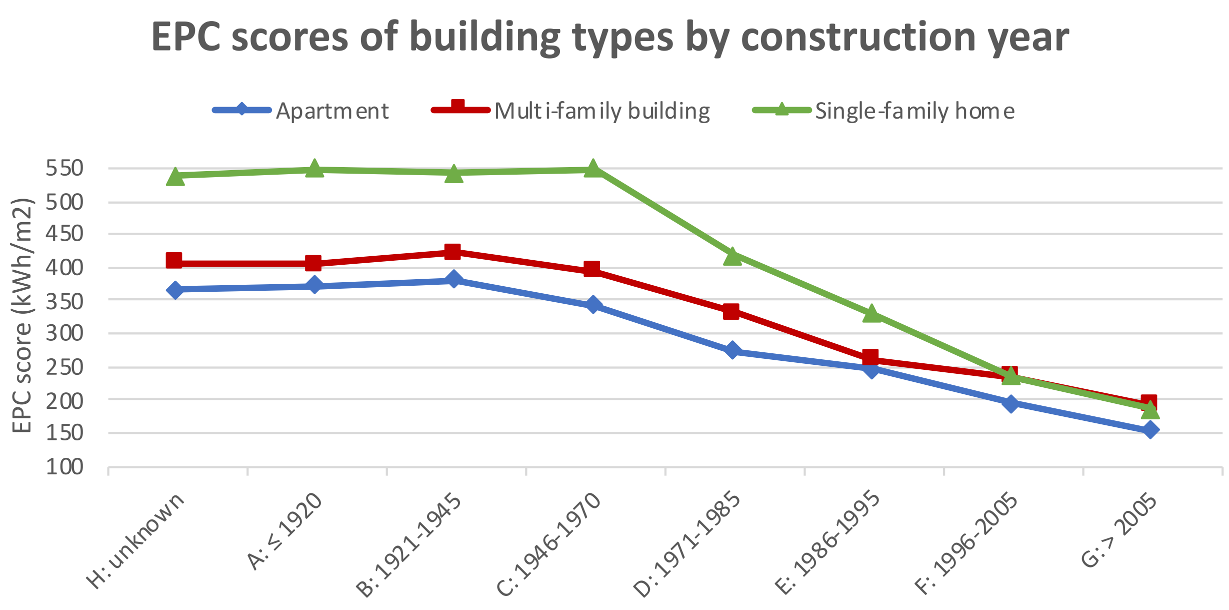

Figure 31: Development of the EPC score with the construction year of the building (Vlaamse Overheid, 2017).

R5 Number of rented social housing units

Social housing is one of the possibilities to mitigate homelessness, as reported in indicator I1. Additionally, social housing is an important government tool to keep housing affordable. In Flanders, social housing companies (SHM) and social housing offices (SVK) provide social housing units. SHMs mostly own and administrate housing units themselves and are obliged to offer the majority of units within the social housing system. SVKs rent real estate from landlords to sublet the units to people eligible for social housing. The Vlaamse Maatschappij voor Social Wonen (VMSW; Flemisch Agency for Social Housing) offers data about social housing online [26]. Figure 32 summarizes the total number of rented social housing units, thus, excludes units of SHMs that were not rented within the social housing system, or social housing units that were vacant by the statistic's reference data (31 December).

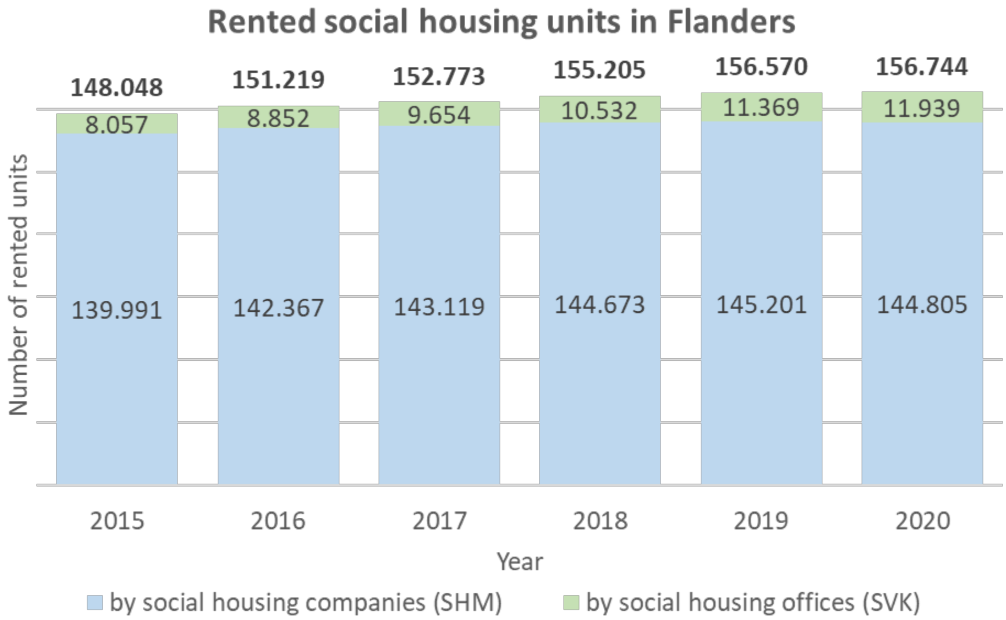

Figure 32: Units rented within the social housing system by social housing companies (SHM), and social housing offices (SVK) [26].

R6 Number of renovations and repairs

The 9R-framework initiates strategies for the way to a circular economy (Potting et al., 2016). In the real estate sector, some of the R-strategies are a matter of course, given the high prices for apartments or houses, as products of the fulfillment system. While repairs are mentioned explicitly in the framework, building renovations would fall under the "Refurbish" strategy, thus restoring the product and bringing it up to date. The heating efficiency indicator (R4) shows that the heating energy consumption can be reduced significantly with modern materials and insulation techniques. Assuming that they have a lower material demand, renovations should be favored over new builds. Figure 33 depicts that **19.851**, or 43,3 %, of all permits issued in 2019 were renovation and not construction permits. However, this number only accounts for severe renovations that legally require a permit. A count of the other renovation works in Flanders do not exist.

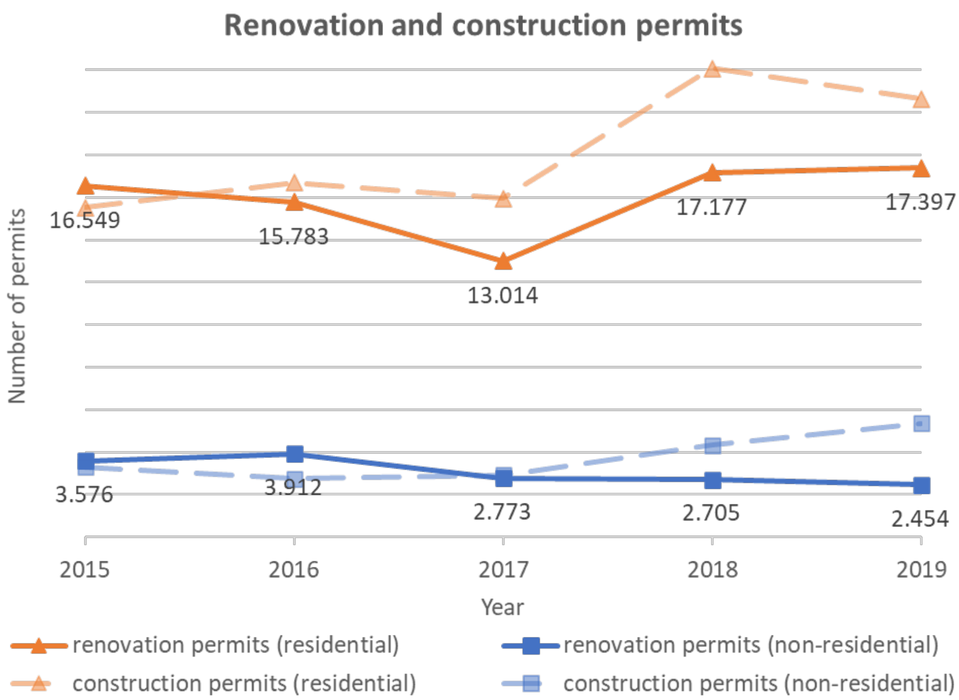

Figure 33: Renovation (solid line) and construction permits (dashed line) for residential (orange) and non-residential (blue) buildings [8].

The number of repairs undertaken in a house or apartment is laborious to measure. Also, public statistics just provide an insufficient picture. The number about expenditure through household consumption by COICOP category lists expenditures on maintenance and repairs of the dwelling. However, these expenditure values are incomplete, as the consumption for this statistic is tracked within a certain survey time of one or two weeks. Repairs happen occasionally after something cracked or broke down. These irregular expenditures are tracked poorly through this survey method. So, no useful number or proxy can be provided for repairs of real estate property.

R7 Average lifetime of buildings

In general, it is more substantial to keep a product in use as long as possible. One of the major ideas in the circular economy is to extend the lifespan of products and their parts. Due to their investment costs, buildings naturally have a long use phase.

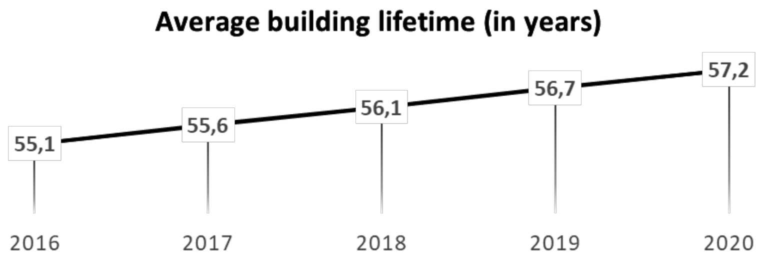

Figure 34: Average lifetime of buildings in years [4].

Figure 34 shows that the lifetime of buildings in Flanders is increasing, although new, and thus young, buildings are constructed every year. These new buildings are obviously an addition to the building stock, instead of drastically replacing older buildings. The numbers in Figure 34 were calculated based on the number of buildings categorized by construction year class provided in Statbel’s “Gebouwenpark” statistic [4]. In 2020, more than 213.000 buildings erected before 1900 still existed. For the computation, it was assumed that the weighted average construction year in that construction year class lies close to the year 1890. The statistic also neglects renovations, so a newly renovated building does not change its construction year class. Of course, the old building stock also implies a challenge for the heating efficiency, as discussed previously.

R8 Share of supervised demolitions

In Belgium, demolitions of non-residential buildings larger than 1.000 m^3 or mainly residential used buildings bigger than 5.000 m^3 have to be supervised. In supervised demolitions, a demolition management organization prepares a demolition plan before the actual destruction action. This plan is a tool to selectively demolish and collect on the site, thus should improve the quality of waste streams and increase recycling rates. The plan includes the demolition site and all waste materials that will be released during demolition or dismantling. For every waste, the plan records

- a description,
- the corresponding EURAL code,
- the estimated quantity,
- the location within the building where the waste occurs, and
- its appearance, form, or shape.

Due to the regulation, just generally big buildings have to undergo a supervised demolition process. The majority of the buildings in Flanders, namely single-family houses, can be demolished without any permission. Accordingly, data about demolition in Flanders is limited, and in hands of private companies in the case of big buildings.

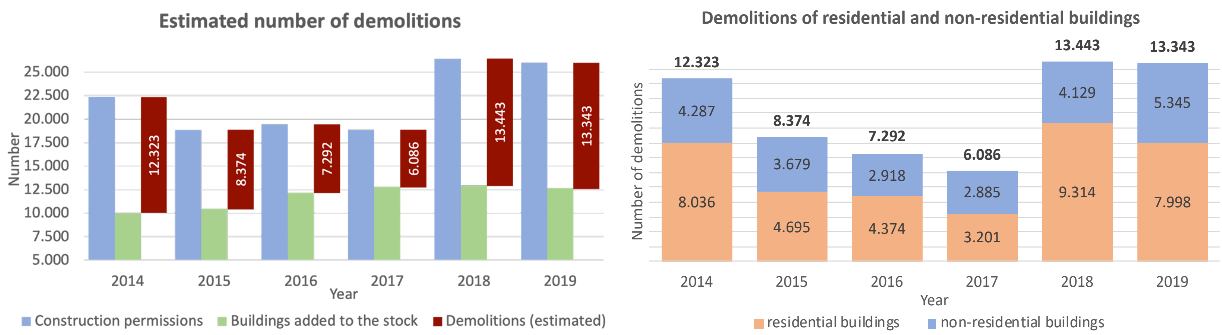

Figure 35: Number of demolitions estimated on the number of issued construction permissions and actual change in the building stock.

Based on the issued construction permissions and the actual change in the building stock over the years, the number of demolitions was estimated. Statbel’s “Gebouwenpark” statistic also includes not yet finished buildings. Thus, for this calculation, it is assumed that the construction works started within the same calendar year the permit was issued. Figure 35 depicts the results of the calculation. Certainly, the shown figures are not exactly the number of demolitions every year, but they become more valid considering several years. Unfortunately, numbers of how many supervised demolitions are done annually are not available. Companies offering demolition supervision, such as Tracimat, might offer interesting data about demolitions and their waste streams, however, these data are not available yet.

In Flanders, rubble waste is categorized into two classes: **h**igh and **l**ow environmental risk profile, short **H**MRP, and **L**MRP. The origin of the HMRP rubble is unknown, there are no guarantees about the quality, and processing the debris is more expensive. On the other hand, the origin of the LMRP rubble is known, its quality is guaranteed and the debris crusher can process easier, thus cheaper. Construction waste undergoing the supervised demolition process is classified as LMRP rubble. So, the share of LMRP waste within the inert waste material stream is an indirect parameter for this indicator. In 2019, Certipro and Copro, an organization certifying crusher facilities, reported to OVAM that 15.782.956 t of rubble was processed, whereof 5.050.133 t was LMRP waste. This would represent **32,0 %** of the rubble waste stream. It is important to mention that not the entire amount of the 5,1 million tons came from demolition sites; production lines and infrastructure projects also contributed to that number. For example, only 64,4 % of Certipro's LMRP rubble, came directly from supervised demolitions.

R9 Recycling rates of building materials

Every two years, OVAM analyzes the commercial waste by surveying a sample of companies [27]. In 2018, OVAM extrapolated that the construction sectors caused 4.496.003 t of waste and 168.065 t of secondary raw materials, entirely minerals. In the statistics, OVAM summarizes the companies by commercial sectors based on the NACEBEL2008 code. The OVAM sectors considered for this study are "bouw", "bouwinstal", and "bouwafwerk". As shown in Figure 36, the vast majority of the waste of these construction enterprises consists out of inert waste, like concrete, bricks, or tiles. Most of the companies do not specify the waste treatment in the survey and just report "other waste treatments".

Waste category	Amount (in tons)
Inert (concrete, bricks, tiles,…)	2.641.840
Earth	968.429
Mixed	144.612
Wood	137.517
Plants, animals	134.585
Metals	113.441
Household	96.698
Minerals	73.021
Tar	37.166
Asbestos	36.822
Paper	30.203
Glass	17.369
Secondary raw materials	168.065
Total	**4.496.003**

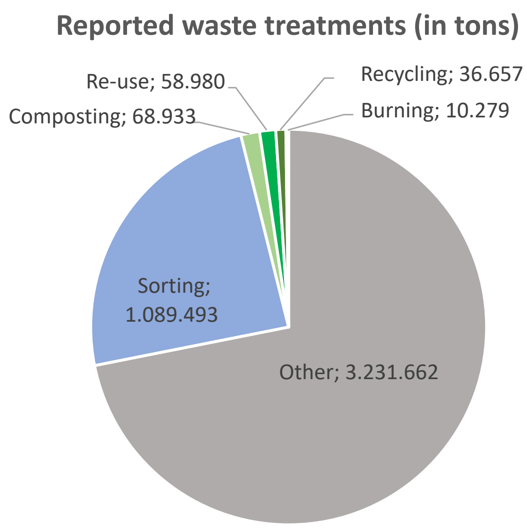

Figure 36: Composition of the commercial waste and its treatments reported by the construction sector companies to OVAM in 2018 [27].

Additional to the commercial waste of the companies, the 2.720.424 t of demolition waste reported by Certipro and Copro has to be added. OVAM also reports 385.062 t of inert waste collected by the municipalities from the households (Raes, Vervaet, et al., 2020). This would sum up to **7.601.489 t** of waste allocated to the building need system. However, the numbers are uncertain to a large extend. The case of inert waste going to a sorting facility first, and then to a crusher, causes double counting in the statistics. Also, an unknown amount of HMRP rubble waste cannot be allocated to the building need system, as the origin of this debris is unknown by definition. Applying the shares calculated from the LMRP rubble, it is reasonable to assume that another 8,6-7,6 million tons of rubble originate from the building sector.

Although more detailed information about the waste treatment of buildings is not available, it is reasonable to assume that the majority of crushed rubble is used as granulates and alternative raw material instead of virgin surface minerals (Figure 37). OVAM reported for 2016 a recovery rate of **96,6 %** of inert waste (Raes, van Pelt, et al., 2020). This includes, besides recycling, also energy recovery. In the construction sector, the only material which has to be landfilled is asbestos, with the amount of 64.924 t in 2018. Despite the high recovery rates, virgin materials still have to be excavated to fulfill the building need system.

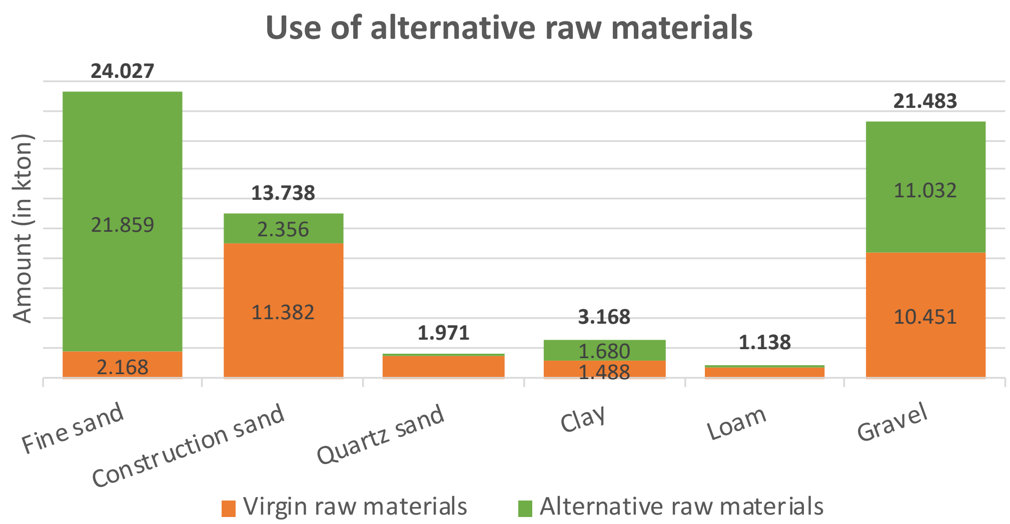

Figure 37: Use of virgin and alternative surface raw materials in 2015 (Schoofs et al., 2016).

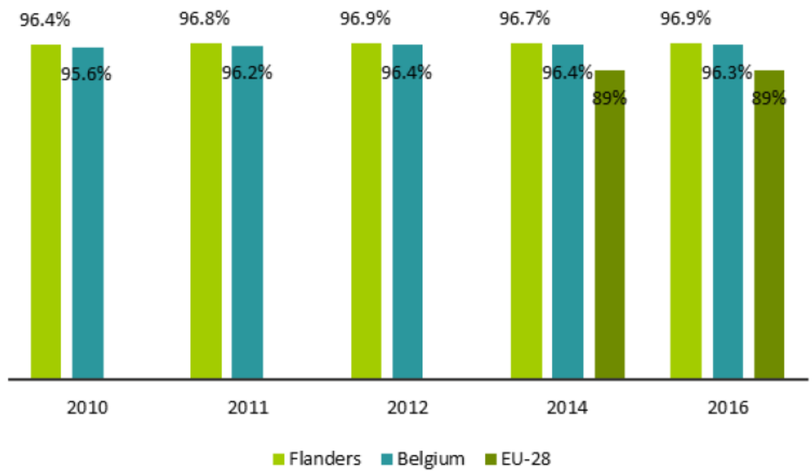

Figure 38: Recovery rates of inert waste streams reported by OVAM (Raes, van Pelt, et al., 2020).

5. CE Monitor for buildings and housing

D1 Number of households D2 Number of enterprises	**D3 / D4 Total floor area of non-/residential buildings**	**D5 Total floor area of all buildings**
2.845.252 1.010.635	1.224.260.838 m² ?	?
P1 Material footprint	**P2 Emissions emitted for building and housing**	**P3 Area of built surface**
> 34.746 kton 8.809 kton	> 22.655 kton CO_2eq > 27.099 t $PM_{2,5}$eq	387.748 ha
S1 Tons of raw materials, fuels and water reserves	**S2 Emission concentrations**	**S3 Area of natural land**
Loam: 18.600 kton Clay: 24.200 kton Sand: 911.900 kton Iron, Oil, Gas: 0 kton	CO_2: 415 ppm PM_{10}: > 20 µg/m³ $PM_{2,5}$: > 10 µg/m³	974.807 ha
I1 Number of homeless people	**I2 Number of people affected by emissions**	**I3 Number of people facing water scarcity**
5.456	CO_2: 6.516.011 PM_{10}: 6.255.371 $PM_{2,5}$: 6.516.011	1.372.283
R1 Raw materials efficiency	**R2 Surface efficiency**	**R3 Use efficiency**
?	7.156 m²/ha ?	93,7 % ?
R4 Heating efficiency (kWh/m²)	**R5 Number of rented social housing units**	**R6 Number of renovations and repairs**
293, 386, 489 ?	156.744	19.851
R7 Average lifetime of buildings	**R8 Share of supervised demolitions**	**R9 Recycling rate of building materials**
57,2 years	31,8 %	96,6 %

Residential buildings
Non-residential buildings

Increasing trend
Decreasing trend
Constant trend

Trend not available
Good development
Bad development

6. Discussion and Outlook

The previous chapter describes a first attempt to draft a set of indicators for the buildings and housing fulfillment system in the context of the transition towards a circular economy in Flanders. Several limits and challenges on data significance, data availability, and data quality arose during this study. In the following paragraphs, these limits and challenges are discussed in more detail and possible mitigations are proposed.

In general, societal need fulfillment systems, or driving forces in the DPSIR framework, are hard to number, as need system sizes are per se immaterial. In the case of residential needs, the number of households is a good indicator, because one household occupies one housing unit by definition, and the data availability and data quality provided by Statbel is convenient. On the other hand, the non-residential needs are indicated poorly by the number of enterprises. The number of enterprises itself does not allow a conclusion on the amount of real estate demanded. While one enterprise might offer its service from a private apartment, a different company might need enormous production halls. Also, the number of employees only provides limited insights into the size of the need. A one-man business, e.g. hairdresser, might rent as much floor area as a four-person sized office. Especially in the case of non-residential buildings, the total floor area built in Flanders would be necessary, but this data is not collected at all. Additionally, the built floor area is a common figure of the construction industry. Normally, the building elements and the construction material needs are set in relation to the floor area, also visible in Figure 12 and Figure 13. This study calculated a proxy for the total floor area of residential buildings based on the reference floor area of the Belgian standard building types categorized by construction year class. However, this is not possible for non-residential buildings, leaving a major data gap.

The material footprint indicator (P1) plays, as in every need fulfillment system, a central role in this study. Based on the outcome of this indicator, the caused emissions (P2) and the raw materials efficiency (R1) can be computed. Because a building is a product consisting out of many materials and different material types, the supply chain is long and widespread. As mentioned earlier, building elements and thus construction material data require information about the built floor area. So, the material footprint again depends on the result of the driving force indicators. Because of the data gaps in indicator D4, this study estimated the material footprint for residential and non-residential buildings with two different approaches. Residential buildings were simplified to the four major materials used for construction according to the result of a Dutch study, while non-residential buildings were modeled as a multi-story building by an Ecoinvent process. In the case of residential buildings, a decent Life Cycle Assessment would be possible with the data given. However, this assessment would be meaningful if the material composition of the Dutch study is similar to Flanders. Based on the building types provided by the TABULA WebTool [5], the element description in the TABULA values sheet [28], and the material composition of buildings' elements in the Nationale Milieudatabase [29], a rough comparison of the building shells in Belgium and the Netherlands can be made (Figure 39). The results of this comparison are summarized in Figure 40.

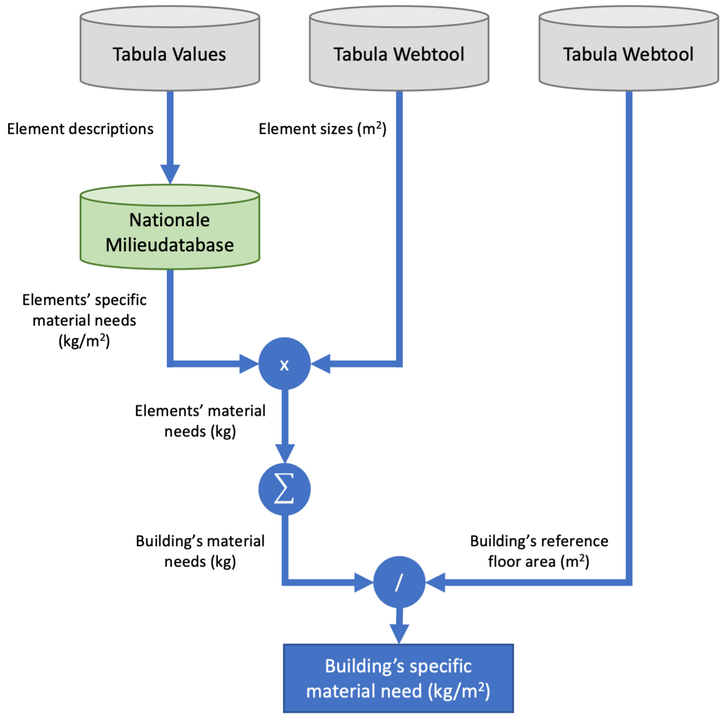

Figure 39: Computation method to compare building shells in Belgium and the Netherlands [28], [29].

	Detached house		Terraced house		Multi family house	
	BEL	NED	BEL	NED	BEL	NED
Reference floor area (m^2)	229 m^2	186 m^2	170 m^2	137 m^2	2151 m^2	3032 m^2
Material need (kg/m^2)	805,6 kg/m^2	764,1 kg/m^2	675,7 kg/m^2	631,6 kg/m^2	815,9 kg/m^2	668,6 kg/m^2
Share of concrete	72,3 %	70,5 %	80,3 %	85,4 %	82,9 %	92,2 %
Share of bricks	13,9 %	16,7 %	9,5 %	5,5 %	10,4 %	4,0 %
Share of wood	1,9 %	1,3 %	1,4 %	1,6 %	0 %	0 %
Share of steel	1,0 %	0,8 %	0,9%	0,9 %	1,0 %	1,0 %

Figure 40: Comparing building shells in Belgium and the Netherlands based on the information provided by the TABULA project and the Nationale Milieudatabase.

The numbers in Figure 40 differ from the specific weights shown in Figure 12. As TABULA is a project focusing on the heating efficiency of residential buildings, no information about the building insides is provided. While Metabolic's study includes interior walls dividing floors, electrical installations, and water supply, TABULA reduces buildings to their shell and heating system. The comparison with the Netherlands shows that Metabolic's study results are a fair approximation at the first glance, but should be replaced by building compositions specific to Flanders. However, data for this still needs to be collected. Of course, such data would improve the results of non-residential buildings in this study a lot, as the Ecoinvent model is not sufficient for obtaining more precise values.

The material and carbon footprint results of this study both differ from the estimated values in Figure 2. The reason for that is that the results were obtained by vastly different methods. The material footprint values are based on the statistics about expenditure through household consumption by COICOP categories of the National Bank of Belgium. Through extensive modeling and extrapolation, the spent Euros shown in the statistics is converted to tons of material used. Contrariwise, this study attempts a bottom-up approach following the Total Materials Consumption idea. Yet, it turned out that this approach still needs a lot of assumptions and not regionalized data to compute a result. The material footprint in this study also includes non-household consumption of the fulfillment system, but it neglects impacts of many aspects related to buildings, such as repair works or real estate services. Also, the emission calculated in this study cannot be allocated to Flanders entirely. They are caused at the production site of the heating energy or construction material.

Data about raw material reserves in Flanders are generally outdated or do not exist. Loam, clay, and gravel are widespread resources with high availability. Nevertheless, they are fundamental for the supply chain of buildings and the building fulfillment system. An official estimation of the total reserves in Flanders would be desirable. Although Statbel provides an official statistic about land use in Flanders and Belgium, its values rely on the land register. The smallest unit in the land register is a parcel, and, thus, the information resolution is limited. For example, the statistic also includes gardens around single-family houses as part of the building. The processing of satellite images might provide more detailed data of land use soon. However, the obvious development of expanding built surfaces at the cost of woods and grassland is not sustainable. Further, a responsible society should look after their least. So, the lack of data about homelessness in Flanders should be mitigated too.

The quality of many response indicators relies on the results of other indicators. In general, it can be claimed that data about non-residential needs and buildings is very incomplete, although their footprint might as be as significant as the residential one. Unfortunately, several response indicators cannot be computed or approximated for the non-residential case. Definitely, more information about the non-residential building sector should be collected.

Surveying repair activities in buildings are laborious. In this regard, the public statistic about expenditure through household consumption by COICOP category provides an insufficient picture. These expenditure values are incomplete for household repairing, as the consumption for the statistic is tracked within a certain survey time of one or two weeks. Repairs happen occasionally after something cracked or broke down. These irregular expenditures are tracked poorly through this survey method. To mitigate this, either an explicit survey about repairs in real estate is undertaken, or cooperation about the data collection of how much material is sold by building material retailers is initiated.

Figure 41 gives an overview of the general indicator data quality in this study. It shows clear data gaps and evaluates the data quality of the indicators or their proxy.

ID	Indicator description	Indictor data quality
D1	Number of households	official data (Statbel)
D2	Number of enterprises	official data (Statbel)
D3	Total floor area of residential buildings	proxy (fair)
D4	Total floor area of non-residential buildings	data gap
D5	Total floor area of all buildings	data gap
P1	Tons of virgin raw materials, fuels and water excavated for buildings and housing	proxy (improvable)
P2	Emission emitted for buildings and housing	depending on P1
P3	Area of built surface	official data (Statbel)
S1	Tons of virgin raw materials, fuels and water reserves	outdated data
S2	Emission concentration	official data (VMM, NOAA)
S3	Area of natural land	official data (Statbel)
I1	Number of homeless people	data gap
I2	Number of people affected by emissions	official data (VMM)
I3	Number of people facing water scarcity	NGO data, only for Belgium
R1	Raw materials efficiency (tons of raw materials used per square meter of buildings)	data gap, depending on P1
R2	Surface efficiency (square meters provided per surface area)	depending on D3, D4, D5, and P3
R3	Use efficiency (share of square meters occupied)	data gap
R4	Heating efficiency (avg EPC score)	official data (EPC database)
R5	Number of rented social housing units	official data (VMSW)
R6	Number of renovations and repairs	data gap
R7	Average lifetime of buildings	official data (Statbel)
R8	Share of supervised demolitions	data gap
R9	Recycling rates of building materials	official data (OVAM)

Figure 41: Overview of the general data availability of every defined indicator.

The set of response indicators should be dynamic and develop new indicators constantly, following the newest policies to improve the results of the other indicator types. New response indicators might arise from the concept of more circular buildings, or give more details in specific aspects of the fulfillment system. With new data gathered the following response indicators might be insightful, and, thus, should be considered in the upcoming development of the monitor:

- Use of renewable bio-materials: As shown in Figure 40, the share of wood materials in building shells is considerably low. Probably this will change with building designs taking circularity more into account. In general, more data about building compositions would enhance many indicators in the monitor. Also, arising concepts, such as building materials as CO2 sinks should be included in a future set of response indicators.
- Amount of reused construction elements: As one of the crucial 9R-strategies, the monitor should number the reuse of construction elements. However, only rough estimations exist in this regard. Thus, an indicator should be developed with the rise of data availability.

- The indicator about recycling quality: Although indicator R9 exhibits high recycling rates, no information about the recycling quality is provided. Especially for inert materials, it is expected that the share of downcycling is certainly dominating. Often, crushed granulate is used as a filler material or gravel alternative. Precious materials with specific properties, e.g. in insulation, heat conduction, or strength, are lost in low-tech applications. Although energy recovery represents a quite linear material stream, it is also included in the reported recycling rates so far. Data and information on the recycling processes and further usage of the recycled materials are needed here to provide more insights on down- and upcycling. Partially, the LMRP-HMRP-rubble initiative tries to mitigate downcycling, but the producers of construction material also have to make use of the new possibilities.

In the other fulfillment systems, the idea of "product as a service" is discussed to make the system more circular. In the building sector, this is already a reality for centuries. Re-using an apartment after a tenant moved out is one of the principles of the real estate market. However, the durability of dwellings, thus the decrease of repair needs, still can be improved. Further, the Ellen MacArthur Foundation suggested viewing a building more as a stack of layers that can be owned by different stakeholders and thus maintained differently to reduce the impact of upkeep (Acharya et al., 2020).

7. Conclusions

Considering each building separately, the building and construction sector might seem quite circular, presenting high recovery rates and long product lifetimes of buildings. Analyzing the whole building fulfillment system, one sees that the needs are growing, buildings expand at the costs of natural land, and more virgin material is excavated for buildings than recycled. Thus, the building stock in Flanders is still growing at the costs of natural land, displacing the habitat of animals, and big amounts of virgin raw materials, especially water, gravel, clay, limestone, and sand, are excavated for it. A shift towards more surface efficient building types, and more advanced sustainable R-strategies, like reuse, should be fostered. For sure, several aspects are improving in a substantial way, such as the heating efficiency of residential buildings (Breemersch et al., 2020), but still many aspects have to be encouraged towards the circular economy. Concerning the building and housing need system in Flanders, this study showed:

- The concept of circular economy is more than material streams and sustainable strategies. It comprises a fundamental shift of the economic system, thus, also implicates social-economic shifts, besides the environmental impacts. All those impacts, environmental, economic and social ones, should be reflected in a CE monitor. This study shows with homelessness only one social dimension of buildings and housing. Future versions of this CE monitor should develop more social indicators to cover a broader picture of the social impacts. Also, impacts on the wildlife and animal species are not included in the monitor yet and should be added in the future.
- Some aspects of the circular economy of buildings and housing are measured poorly by the indicators proposed in this study. For example, the driving forces for non-residential real estate are reflected by the numbers of companies with a tax number in Flanders. This approach neglects companies that a headquartered outside of Flanders but open branches in the region. Also, real estate demands of non-profit organizations, educational institutions, sports clubs, and government departments are not covered in this indicator. A better indicator might be the total number of corporate bodies demanding real estate. However, such specific data does not exist yet.
- In many cases, data availability for the proposed indicators is insufficient or is based on different reference years. Notably, data about the total floor area of non-residential buildings and the material needed for the different building types in Flanders are crucial for this monitor. An assessment of the floor area of the building categories (residential, shops, offices, schools, government branches, etc.) might be helpful. Additionally, this database could be kept up to date by collecting the floor area also in the construction permits of non-residential buildings.
- The evaluation of building material stock present in all buildings in Flanders (similar to the study of Metabolic and SGS Search [7]) might improve the quality of the material and carbon footprint indicator, computed bottom-up, significantly. Also, the material stock might be interesting for several CE strategies (recycling, reuse, urban mining) and it would reveal trends and advancements in circular construction techniques if the evaluation is done in regular intervals. It would also enable the allocation of macro numbers (e.g. recycling rates of material categories) to the building and housing need system. The same challenges are true for data about renovations and repairs of real estate.

- Data about the social aspects of buildings and housing in Flanders are marginal. In this regard, a principle definition of homelessness, for example, and data collection accordingly will be helpful. Additionally, other social impacts, such as affordability, or housing quality, should be discussed and tracked accordingly.
- The set of response indicators should be dynamic and be aligned with policy programs, emission targets, and energy consumption goals. New arising sustainable concepts, such as urban mining, building materials as CO_2-sinks, or reuse of entire, modular building elements, should definitely be incorporated in the CE monitor as soon targets are defined and data is collected.

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Appendix: Indicator calculations

Indicator
calculations (MS Exc

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