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Existing databases as means to explore the potential of the building stock as material bank

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Abstract. Awareness of the huge environmental impact of buildings has created more interest in resource efficiency and in the potential of circular economy. This is not only relevant for new buildings. Also the existing building stock represents a great amount of building materials, which could become available for reuse and recycling in the future. Currently, there is no database in Belgium that reflects the potential of existing buildings as material banks. Nevertheless, existing databases, e.g. the EPC (Energy Performance Certificate) database of the Flemish Energy Agency (VEA), contain valuable information on the material content in the existing building stock. Therefore, this paper explores the possibility of combining existing databases to reflect the (future) potential of the existing building stock as material bank. The two main databases under study are: 1) the EPC database of VEA which contains general building characteristics, such as building volume, building typology, floor area and information on the building envelope of more than 1 million buildings in the Flemish region and 2) the database of Essencia Marketing, a marketing agency specialized in the construction sector, which contains general building characteristics as well as geometrical and material data on almost 6000 new residential buildings spread all over Belgium (constructed between mid-2010 and mid-2017). The data in the databases are discussed and possible methods to combine data from both databases are explored.

Keywords: buildings as material banks, database extrapolation, estimation method, quantities of building materials

1. Introduction

The increasing awareness of the importance of resource efficiency and the growing interest in environmental impact assessment of buildings contribute to the need to consider buildings as (future) material banks. Consequently, the interest in knowing the amount of building materials used in new and existing buildings has increased. For new buildings with a BIM model, building material quantities can be derived easily, whereas for existing buildings with an energy performance certificate (EPC), material quantities for the building envelope are relatively well known. However, for most of the buildings of the existing building stock, no BIM model or EPC is available (yet).

A number of literature studies already analysed the material use in the existing building stock, mostly for a certain region. For instance, Kleeman et al. [1] studied the material stock in buildings in Vienna by means of GIS data. Gontia et al. [2] created a material intensity coefficient database for Sweden as a means to explore the potential of the building stock to serve as a material bank. However, as the composition of the building stock differs per country or even per region, there is a need for more country or region specific databases.

Currently, no database that reflects the potential of existing buildings as material banks is available in Belgium. Nevertheless, other databases exist, which contain valuable information on the existing building stock. Therefore, this paper explores the opportunity of combining existing databases to determine the (future) potential of the existing building stock as material bank. A practical example, which is focussed on the Flemish region in Belgium and on a estimation of the interior wall area in existing buildings, is elaborated.

2. Material and methods

The two databases at stake are the EPC database of the Flemish Energy Agency (further referred to as the EPC database) and the database of Essencia Marketing [3] (referred to as Essencia database), First, an overview is provided with regard to their content, their use and their deficiencies. Next, the specific focus on an estimation method for the interior wall area is discussed. Finally, the possibility of combining the two databases by means of predictive modelling is explored.

2.1. The EPC database of the Flemish Energy Agency

As a result of the introduction of the Energy Performance Certificate (EPC) in November 2008 for houses at sale and in January 2009 for rental houses, the Flemish Energy Agency (VEA) in Flanders, Belgium established a database with the EPC's of existing houses, flats and collective residential buildings. For each building with an EPC, the EPC database contains detailed information on general building characteristics, such as building volume, building typology, construction period and location as well as detailed information on the building envelope, both with regard to surface area and material use. Currently, the database contains data of more than 1 million existing buildings of the Flemish region (almost 50% of the residential buildings).

An EPC is mandatory for each residential unit that is put up for sale or for rent and is valid for a period of 10 years. It can only be established by a certified energy expert who has to follow an inspection protocol to determine the specific characteristics of the building and its systems. The protocol defines how use of materials, presence of insulation, type of windows, etc. have to be determined and how the expert has to deal with incomplete or uncertain information. In case the real situation cannot be determined or the expert is not doing the effort to determine the real situation (e.g. to be more cost-effective), default values have to be used, which often depend on the construction period of the building. It is traceable in the EPC database whether specific data are accurate or based on default values.

For geometrical data, such as building volume, areas of roofs, facades, floors and windows, no default values can be used and this information is collected in a very detailed way (area per individual roof, façade, floor and window). This way, the EPC database represents an extensive collection of geometrical data of residential buildings in Flanders, according to building typology, construction year

and location. However, geometrical data are only available for the building envelope, not for inner walls or floors.

Use of default values is mostly related to the presence of insulation materials. Analysis of the database dd. 2014 (containing 724.345 houses) showed that default values are very frequently used for insulation, especially for older buildings [4]. Knowledge about insulation materials and thickness was accurate at that time for 55% of the roofs (17% no insulation; 38% specific material and thickness known), 52% of the facades (36% no insulation; 16% specific material and thickness known) and 50% of the floors (42% no insulation; 8% specific material and thickness known). For the remaining % it was unknown whether insulation is present or the information on the insulation was incomplete.

Since the EPC is mainly meant to inform future buyers/renters on the energy performance of the building, accuracy on the presence of insulation, thermally insulating windows and heating systems is more important than accuracy on other material use. Therefore to support the energy expert in easily collecting and inserting the data related to the other layers of roofs, façades and floors, the EPC software uses a limited drop down list for the construction type per component: 2 types for the roof, 5 types for the façade, 2 types for the floor, 10 types for the glazing and 6 types for the window profiles. However, most common construction types, such as sloped roofs with wooden construction and ceramic tiles or walls mainly made out of brick are within the list.

This means that the reliability of the information in the EPC database depends on the type of information. It is very reliable with regard to geometrical data of the building envelope, but less reliable with regard to exact material use.

2.2. The database of Essencia Marketing

Essencia Marketing, a marketing agency specialized in the construction sector, developed a database with information on residential buildings through onsite measurements of buildings during the construction phase. During the measuring process, professional measurers go onsite, note the main building characteristics (e.g. building typology, type of house, type of roof, …) and measure the length and height of all building elements with digital measuring equipment (e.g. m² roof, m² exterior wall, m² interior wall, m² window, …). In addition, the used building materials (bricks, tiles, insulation, …) and their brands are registered. The Essencia database was set up in 2010 and is extended on a yearly basis with a sample of approximately 1.000 buildings that is representative for the yearly delivered building permits (per building typology) in Belgium. Therefore, the database can be considered as representative for the Belgian residential building stock produced since 2010. Mid 2017 the database contained data of almost 6000 residential buildings spread all over Belgium. As composing the database involves manual procedures, the data of all buildings are checked on completeness and credibility: buildings with missing data for the relevant parameters and buildings with unrealistic values for the main structural elements (e.g. a house length of more than 50m) are omitted in the following analyses. After this data cleaning, 4963 buildings remain, being 4508 single family houses and 455 apartment buildings.
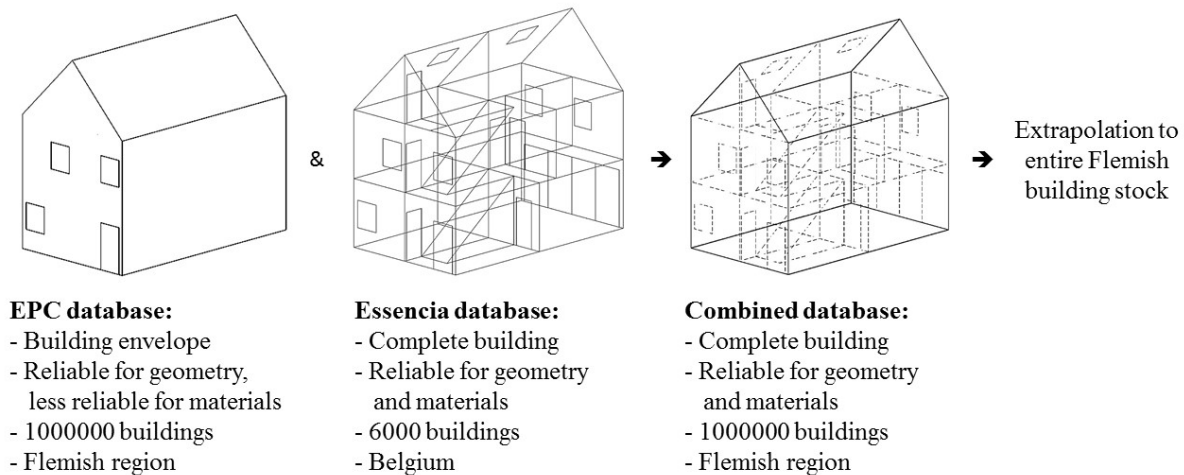
The data in the Essencia database are extrapolated to the entire share of newly built residential buildings in Belgium on a yearly basis. This information is used to provide manufacturers of building materials with insights on the market share of their building materials per year and on the evolutions or changes in material use of the market. Similarly, this information could be used as input to compose a BAMB database for Belgium.

However, in the Essencia database, no information is available for buildings younger than 2010. In addition, adaptations or renovations (and the associated material flows) in a later life cycle phase of the building are not considered.

2.3. Combining the databases

Both the EPC database and the Essencia database contain valuable information about the Flemish/Belgian building stock. The EPC database is the most extensive one, but it only contains general building parameters and data on the building envelope and is mostly reliable with regard to

geometrical data. The Essencia database is less extensive and it only contains data for buildings, constructed after 2010, but the data per building are more complete, also with regard to material use. Therefore, combining both databases and extrapolating the findings for the entire Flemish building stock could be a starting point to explore the potential of the existing building stock to serve as a material bank for the future (figure 1). It can be assumed that the Walloon region and Brussels Capital region dispose of similar EPC databases as the one from the Flemish region. Hence, in a later stage, the findings could also be elaborated for those EPC databases.


EPC database:
- Building envelope
- Reliable for geometry, less reliable for materials
- 1000000 buildings
- Flemish region

Essencia database:
- Complete building
- Reliable for geometry and materials
- 6000 buildings
- Belgium

Combined database:
- Complete building
- Reliable for geometry and materials
- 1000000 buildings
- Flemish region

Figure 1: Achieving a combined database to fill in the data gap.

As an example of the potential of the combination of both databases, this paper presents the development of estimation method for the interior wall area in Flemish houses, based on combining data from both databases.

In the EPC database, information on the interior building elements such as intermediate floors and interior walls is lacking. For the estimation of the intermediate floor area of a building, a simple multiplication of the building footprint and the number of floors might suffice as a rough estimation. However, an estimation of the interior wall area is more complex. Since the Essencia database has more complete data on interior building elements, formulas have been derived for the estimation of interior building element quantities based on general building parameters and building envelope data. Since these data are easily available in the EPC database, by applying the estimation equation from the Essencia database to the EPC database, it is possible to estimate the material quantities related to interior walls in Flemish residential buildings.

2.4. Estimation of the interior wall area
In the present paper, the interior wall area refers to the area of all interior walls in the building, including the inner leaf of exterior (party) walls, minus the area of windows and doors (figure 2).
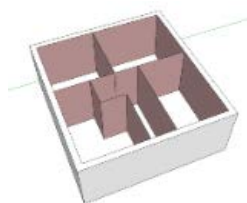
Figure 2: Definition of the interior wall area, consisting of both the interior part of exterior walls and the interior walls.

Currently, little information on the interior wall area in buildings can be found, even though the net quantities of interior wall area materials are almost twice as high as the net quantities of exterior wall area in single family houses [3]. Especially for the interior wall area, which often consists of the sum

of several smaller areas, detailed calculation of material quantities is very time consuming and difficult. In practice, there is no uniform calculation format; most actors use a self-developed calculation module or rules of thumb.

Therefore, an estimation equation for the interior wall area has been developed by using predictive modelling through the R^2 k-fold method. The R^2 is often used as a measure of goodness of fit: the higher the R^2-value, the more the equation can be seen as a valuable predictor [5]. By the k-fold method, the dataset is divided in "k" subsamples. A single subsample is retained as the validation data for testing the equation, and the remaining "k – 1" subsamples are used as training data. In this study, the dataset is split into five subsamples (k=5). The analyses are conducted in JMP Pro 13.2.0, a software for predictive modelling and validation [6]. The robustness and precision of the equation was validated three times. Firstly, the prediction of interior wall area was checked for alternative (more simplified) ways of calculating the building volume; secondly, the equation was tested on an extension of the Essencia database, and thirdly, the equation was checked on an unrelated database with 75 single family dwellings that also contains data on both building envelope, building volume and interior building elements.

3. Results and discussion

3.1. Estimation equation for the interior wall area
Analyses on the Essencia database show that the building volume, by far, the most important variable seems to estimate the interior wall area. The fit between the interior wall area and the building volume per building is illustrated in figure 3. Hence, the building volume is considered as the most important predictor for the interior wall area. Estimation equation (1), based on the building volume combined with the extra parameters 'building typology' and 'type of house', provides the best result (with R^2 k-fold = 0.88). However, the contribution of the extra parameters can be seen as statistically significant, but practically irrelevant. Therefore, a simplified estimation equation (2), based on only the volume of the building, can also be applied (R^2 k-fold = 0.87).
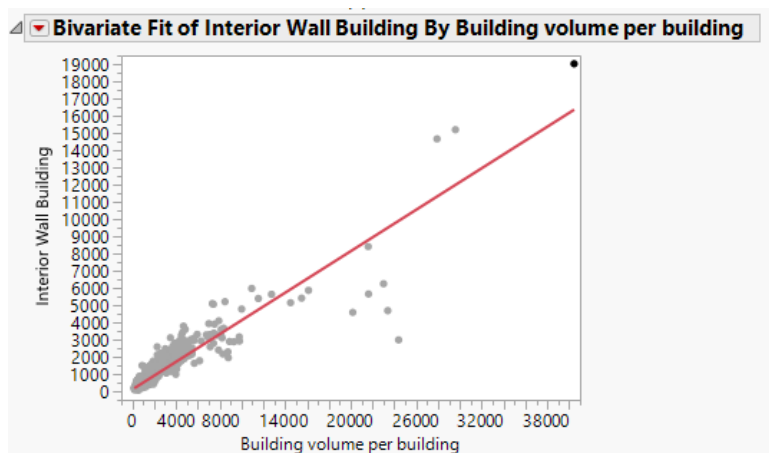

Figure 3: Bivariate analysis of Interior wall area per building (in m²) and the Building volume per building (in m²).

$$\textit{Interior wall area per building in } m^2 = 275.9 + 0.37 * \textit{building volume per building in } m^3 \quad (1)$$
$$+ \textit{(building typology: "terraced" 19.6, "semi-detached" 0.11, "detached" -19.7)}$$
$$+ \textit{(type of house: "Apartment" 166.4, "single family dwelling" -166.4)}$$

$$\textit{Interior wall area per building in } m^2 = 106.58 + 0.40 * \textit{building volume per building in } m^3 \quad (2)$$

To validate both estimation equations, they were applied to an independent database containing information on 75 single family dwellings (figure 4). It is found that, even when underlying data are changed, the mentioned estimation equations remain accurate: estimation equation (1) on average leads to a slight underestimation of the real interior wall area, whereas estimation equation (2) on average results in a slight overestimation of the real interior wall area. Nevertheless, both estimation equations seem suitable for the prediction of the interior wall area in a building in case this information is not available.
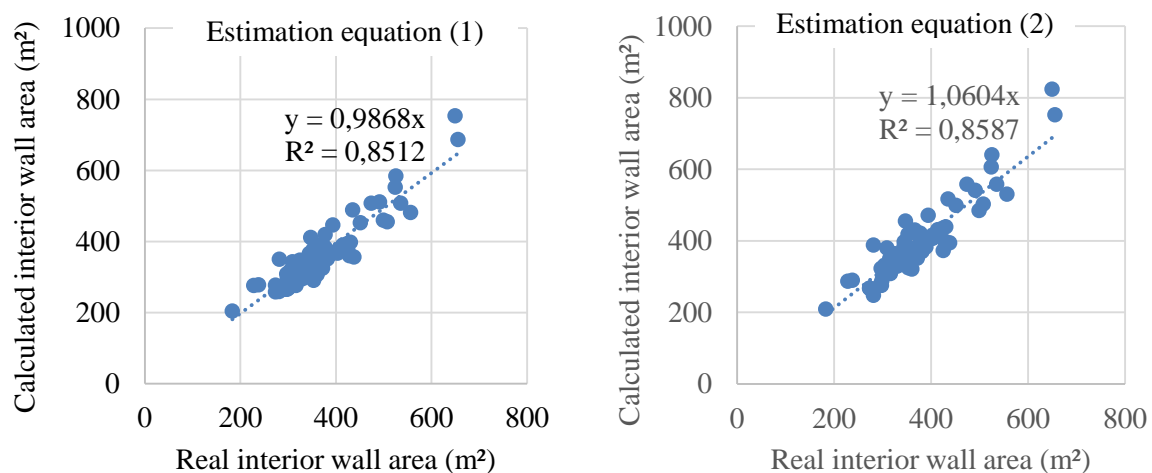
Figure 4: Correlation between the real interior wall area (m²) and the calculated interior wall area (m²) by means of the estimation equations (1) and (2) when applied to an independent database (N=75). Left = Estimation equation (1) based on building volume, building typology and type of house; Right = Estimation equation (2) with only building volume.

3.2. Application to the EPC database and further extrapolation

As already mentioned, the EPC database contains information on the building volume and building typology of more than 1 million residential buildings of the Flemish region constructed before 1900 until present. Hence, the average building volume per building typology and per construction period is available. By applying the estimation equations derived from the Essencia Marketing database to the building volume averages of the EPC database, an estimation of the interior wall quantities used in the entire Flemish region could be derived. Table 1 gives first an estimation based on equation (1) and the average building volume for terraced, semi-detached and detached houses from the EPC database (dd. 2014) and an extrapolation to the entire Flemish building stock. The last 3 rows in table 1 give an estimation based on equation (2) and the average building volume for single family houses from the EPC database and an extrapolation to the entire Flemish building stock.

Table 1: Exemplary application of the estimation equation from the Essencia database on the EPC database according to estimation equation (1) and estimation equation (2) with further extrapolation for the Flemish dwelling stock.

Parameter	Est. eq. (1)
Average building volume in Flanders of a terraced house (in m³)[a]	460
Quantity of interior wall area per terraced house (in m²)	299.30
Extrapolated interior wall area for terraced houses in Flanders (in m²) (n= 647 144)[b]	193 690 199
Average building volume in Flanders of semi-detached house (in m³)[a]	474
Quantity of interior wall area per semi-detached house (in m²)	284.99
Extrapolated interior wall area for semi-detached houses in Flanders (in m²) (n= 570 240)[b]	162 512 698
Average building volume in Flanders of a detached house (in m³)[a]	613
Quantity of interior wall area per detached house (in m²)	316.61
Extrapolated interior wall area for detached houses in Flanders (in m²) (n= 887 508)[b]	280 993 908
Total extrapolated interior wall area for the Flemish building stock (in m²) (n= 2 104 892)[b]	**637 196 804**
	Est. eq. (2)
Average building volume in Flanders of a house (in m³)[a]	519
Quantity of interior wall area per house (in m²)	314,18
Extrapolated interior wall area for the Flemish building stock (in m²) (n= 2 104 892)[b]	**661 314 969**

[a] Verbeeck, G. and W. Ceulemans, Samenvattend rapport: Analyse van de EPC databank. Resultaten tot en met 2014. [4]

[b] Land register of the Flemish dwellings stock on 1/1/2015. [7]

A difference of 4.7% is noticed between the results based on estimation equation (1) and estimation equation (2). These results need to be interpreted with caution, as the structural composition of buildings constructed after 2010 is used to extrapolate the findings to buildings constructed before 1900 until now. An additional check whether the presented estimation equations, derived from the Essencia database, are also valid for older buildings (constructed before 2010) is necessary in future research. With the introduction of building passports in the (near) future, more knowledge on older buildings might become available that could be used for a fine tuning of the presented estimation equations.

Starting from the estimations of the interior wall area (table 1), a further (but less accurate) estimation can be made of the amount of bricks used in interior walls in Flemish single family houses (table 2). This by combining the results of table 1 with an estimation of the market share of e.g. clay bricks. This market share can be derived from the onsite measurements, where the Essencia professionals note beside the main building characteristics also the used building materials and their brands. The same caution is necessary here, as Essencia database only reports since 2010 and contains no information on the market share for older buildings. As long as more accurate information on material contents of existing buildings is lacking, these estimated amounts could serve as input for scenarios for future demolitions and (waste) material flows.

Table 2: Exemplary application of the estimation of the market share of clay bricks used in interior wall area on the Flemish dwelling stock.

Parameter	Est. eq. (1)	Est. eq. (2)
Extrapolation of the interior wall area to the Flemish dwelling stock (in m²)	637 196 804	661 314 969
Estimated market share of clay bricks for interior wall[a]	85.4%	
Estimated amount of clay bricks embedded in the interior walls in the Flemish dwelling stock (in m²)	544 166 071	564 762 983

[a] Essencia Marketing; average market share since 2010 – 2017 in Flanders.

4. Conclusion

This paper discusses the potential of combining two different databases to gain more insights in the material quantities and types used in the existing Flemish/Belgian building stock that might become available for reuse and recycling in the future. The EPC database contains information on a large number of buildings, but is limited to general building parameters and quantities and materials used in the building envelope. The Essencia database is smaller, but contains complete information on the building parameters, element quantities and material types, however only for buildings built after 2010. Two methods to estimate the quantity of the interior wall area, based on the building volume and building typology, are derived from the Essencia database. By applying the estimation equations to the data in the EPC database, an estimation of the interior wall area of a larger set of dwellings can be obtained. However, extra checks, e.g. on the suitability of the estimation equations for older buildings, are necessary. Nevertheless, at this point and with the currently available data, the estimation equations provide the best possible approximation for the interior wall area in the existing building stock. The combination of different databases and the extension of the data availability through predictive modelling and extrapolation could provide a starting point for the development of a BAMB database for Belgium.

5. References

[1]   Kleemann, F., et al. 2017 GIS-based Analysis of Vienna's Material Stock in Buildings. *Journal of Industrial Ecology* **21**(2) pp 368-80.
[2]   Gontia, P., et al. 2018 Material-intensity database of residential buildings: A case-study of Sweden in the international context. *Resources, Conservation and Recycling* **130** pp 228-39.
[3]   Essencia-Marketing 2018 http://essencia.be/en/page/market-information-construction-Belgium.
[4]   Verbeeck G. and Ceulemans W 2015 Samenvattend rapport: Analyse van de EPC databank. Resultaten tot en met 2014 *Steunpunt Wonen* Leuven p 55.
[5]   Renaud O and Victoria-Feser M.-P 2010 A robust coefficient of determination for regression. *Journal of Statistical Planning and Inference* **140**(7) pp 1852-62.
[6]   SAS_Institute JMP n.d. www.jmp.com.
[7]   Economie–Statbel FOD n.d. *Algemene directie Statistiek en Economische informatie* https://statbel.fgov.be/nl/themas/bouwen-wonen/gebouwenpark#figures.

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