B³-RETROTOOL:

DEVELOPMENT OF A MULTI-SCALE AND MULTI-CRITERIA PRE-ASSESSMENT TOOL FOR THE SUSTAINABLE RETROFIT OF BRUSSELS CAPITAL REGION

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ABSTRACT

This research offers a new vision of Brussels Capital Region (BCR) as an Urban Metabolism in which the building blocks are one key element to enhance heritage value, to achieve important improvements in the energy performance and to reduce environmental impact of existing residential building stock. Four scales were integrated in the study: the city, the neighbourhood, the city block and the residential buildings. This research focused on the definition of criteria for each of these scales to identify building and built environment typologies and propose suitable urban or architectural interventions in for each typologies to preserve heritage value reduce relevant energy use and environmental impact.

The main objective of the research is to achieve a pre-assessment tool to retrofit the city, the neighbourhood, the city block and the residential buildings based on an integrated multi-criteria and multi-scale approach in order to meet the environmental, social and economic challenges of the contemporary world and thus foster the transition towards sustainable development

This research also pinpoints the importance of transforming city blocks, as a basic unit of the urban matrix. The originality of this project is thus to identify new determinants in designing modern, economic and efficient city blocks using a multi-criteria and multi-scale approach. The key is probably to consider these aspects in a non-compartmentalized, complementary way, in order to reach a global objective through a sustainable and responsible approach.

INTRODUCTION

Twenty-five years after the publication of the Brundtland Report and twenty years after the publication, in Rio de Janeiro, of the 27 principles defining the concept of sustainable development, issues of resource conservation and limiting emissions (atmospheric or others) are at the centre of many discussions, both environmental, economic or social and more specifically at the urban scale.

In fact, cities mobilize, transform and consume large amounts of natural resources (energy and non-energy resources). As they do so, they exert significant pressure on the environment (removal of energy and materials, releases to air, water and soil) and on the associated political, social and economic scales. Un-refurbished buildings represent a large proportion of the building stock and the first cause of CO2 emissions in the building sector. Residential buildings account for the 60% of final energy consumption in the building sector and 70% of buildings floor area.

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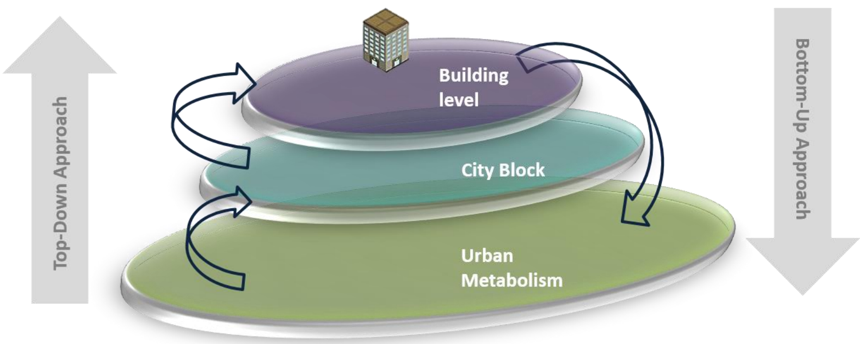
Some considerable progress have been made in the last 20 years concerning the energy consumption of urban transportation, the energy performance of buildings, greenhouse gas emissions, waste production and treatment. Yet, all these issues are generally analyzed in a fragmentary way and overlapping methodological tools are still underused or inexistent. Moreover, little work combines all environmental, economic and social fields to understand the functioning of the city in order to achieve sustainable and resilient urban systems.

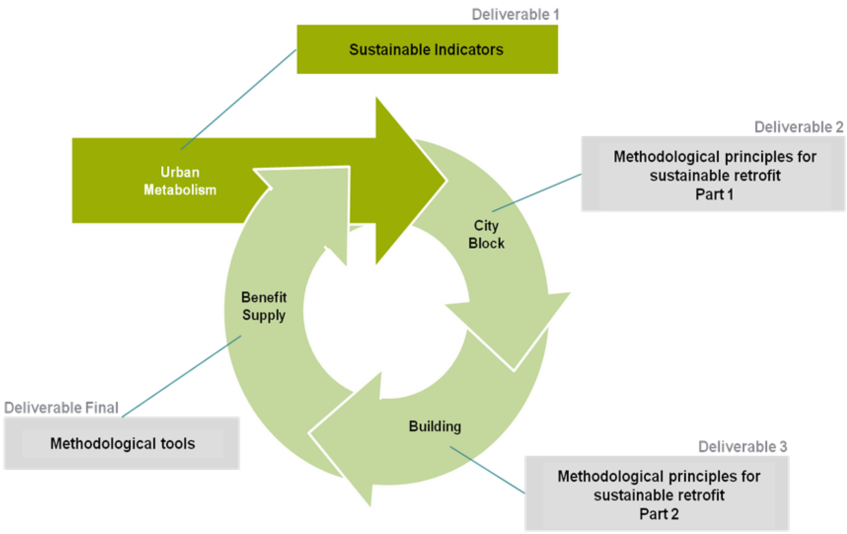
In this context, it is urgent to seek new ways to build and renovate city's infrastructure and superstructure, including consideration of environmental objectives into strategies for sustainable buildings renovation and sustainable management of urban metabolism. However, the renovation or retrofitting of the built environment is not an easy task as it often involves taking into account the local and national heritage.

As a result of these observations, the objective of the project **B³-Retrotool** is to offer a new vision of Brussels Capital Region (BCR) as an Urban Metabolism in which the building blocks are proposed as the key to enhance heritage value, to achieve important improvements in the energy performance and to reduce environmental impact of the existing building stock.
This research attempts to initiate a sustainable transition and accelerate the renovation process by providing a decision making tool, which measures the impact of these processes.
The originality of the research is to offer a holistic and systemic approach to define suitable architectural interventions considering existing urban morphology, city blocks and buildings not only as a huge energy-consumer, but also as a resource for material and innovation. In this contribution the research methodology and the various steps to achieve the main outcome of the project will be presented.

RESEARCH METHODOLOGY

A top-down and bottom-up approach is used to link the scales inside themselves but also in between them in order to validate the hypothesis that, any improvement in whichever of the three levels is immediately perceived in the other two. The project proposal, that there could be integrated actions to be done in homogeneous building stocks to achieve more important impacts at the city scale, is hence reinforced.





1. Evaluation of the Brussels Urban Metabolism

This first part of the research project aimed to provide a general overview of Brussels current state of (un)sustainability from an Urban Metabolism approach. This approach considered the entire Brussels Capital Region as an urban system requiring input (resources) and producing output (waste, pollution, exports) flows. Indeed, this analysis allowed contextualizing the importance and relevance of retrofitting the residential building sector and especially the part built before 1945.

This part of the research included four steps: establishment of an accounting and assessment methodology suitable to Brussels context, data collection, mapping the Brussels' neighbourhood metabolism and proposition of methodological principles for sustainable retrofit.

1.1. Methodology and criteria

This part of research focused on a literature review of the existing methodological tools for integrated environmental assessment of urban areas. In this research mainly three methodological tools came out as suitable in terms of their panoramic scope, namely MFA (Material Flow Analysis) or MEFA (Material and Energy Flow Analysis), Urban Metabolism and Input-Output Analysis. The analysis of some case studies carries out using respectively each methodology, suggests that in the case of Brussels a more hybrid approach is appropriate.

1.2. Data collection

To successfully perform this data collection, most grid operators and statistical centres websites were screening for online data or online annual reports. Very frequently this process was frequently combined with an interview, in order to request further available data or to consult archives, but also to discuss about the reliability and hypothesis of database and finally to enquire for their expertise in the interpretation and clarification of resource use trends.

Some of the institutions that where reviewed and contacted for data collection are:

IBGE (Espaces Verts, Quartiers Durables, Qualité de l'Environnement, Energie), STIB, Hydrobru, Vivaqua, Sibelga, Electrabel, Synegrid, Brugel, Service de Médiation de l'Energie, IBSA (Energie et Environnement, Monitoring des Quartiers), DGSIE (Census, Economic, Housing, Transport), ABP, CIRB, Banque National de Belgique, Bureau Fédéral du Plan, SNCB, Port de Bruxelles, Centre Paul Duvigneaud, CARHOP, …

This data enquiry pinpoints the crucial need for some data to become available (or even to create some data specifically for the research needs) to the researchers of this platform in order to perform precise, innovative and cutting-edge research in energy use and renovation of the built environment.

Nevertheless, it is important to state that the originality of this project lies on its panoramic character that combines a top-down and a bottom-up approach in order to assess the potential and the impact of retrofitting the pre-war building stock.

1.3. Map of Brussels' neighbourhood metabolism

Urban Metabolism (UM) studies are a relatively new and prosperous scientific field that has also gained importance in the administrative and policy sphere. Thus, the objective of this part of research, namely establishing an UM analysis of Brussels at different spatial scales, originally contributes not only in Brussels environmental assessment but also in the academic world.

In practice, relevant data were gathered in order to offer a synthetic view of Brussels Capital Region environmental performance in 2010. Metabolism at regional scale informs us about the sustainability state of Brussels.

The downscaling of the UM at the municipality scale provided valuable and original information such as how the resource consumption and material stock are spatially distributed. This spatialisation illustrated the different behaviours regarding energy (electricity and gas) and water use. Some more obvious relations such as municipalities with the highest number of inhabitants and buildings consume resources the most appeared, regardless of the type of resource. However, consumption per inhabitant (in this project inhabitant was preferred to capita as the contribution of commuters is difficult to estimate and especially spatialise) presented a much different distribution pattern. In addition, this time consumption per inhabitant spatialisation patterns varied from resource to resource (as for instance electricity can also be used for tertiary activities).

In order to better understand the parameters behind these consumption patterns, a number of correlating analyses were performed using either Spearman rank correlation coefficient, factor analysis or principal component analysis. Some of the parameters that were studied in the project are the following: Population (population density, nationality, average age), Households (number, size), Demographic projection, Labour market (activity and unemployment rates, average incomes (per inh/household)), Housing (average size (per person and dwelling), average rent, occupancy), Built environment (density of office space, number of storeys, age of buildings), Mobility (number of cars, distance from public transportation stop), Environment (emissions, waste, energy, water).

The last step was to disaggregate the UM at the level of the statistical sector. This scale will act as a hinge between the city scale and the building block scale, where more relevant information can be illustrated. However, the transition from municipality to statistical sector scale will add some supplementary issues that those encountered at the municipality scale. In fact, at this scale absolute consumption data are not available from grid operators or energy and water suppliers. Thus, resource use at this level is has to be estimated by the absolute values provided at municipality scales. Some factors that were used to downscale consumption data were the number of inhabitants, m² of built area (m² residential + m² offices), and number of dwellings. However, it is important to keep in mind that consumptions can still not be divided in activity sectors. Thus, even if it is possible to estimate the potential resource consumption reduction, it becomes difficult to give precise figures about the energy and water savings through the renovation of pre-war residential buildings.

1.4. Methodological principles for sustainable retrofit (ongoing)

In this part of research, the authors wished to continue even further the correlation analysis by retrieving more precise consumption data at smaller spatial scales. However, after months of negotiations with grid operators and suppliers this was not achieved. Therefore correlations results at smaller scales presented a high uncertainty as precise data were only available at the municipality scale and for all sectors.

As a result, the identification of priority zones where renovation could be most efficient is also very uncertain. An attempt was carried out by downscaling energy (electricity and natural gas) use at the statistical sector level. However, at the scale of the statistical sector it is difficult to propose retrofitting principles as it is too heterogeneous and vast, but also due to the great uncertainty of the data available.

In conclusion, the authors have decided that the methodological principles will be addressed in the scale of the city block which is the hinge between the city level and the building level and it offers the possibility of concrete actions that can actually be implemented by the inhabitants of the city block.

2. Analysis of the city block level

During its history, Brussels has had a very similar urban development to those of other medieval European cities. This is mostly reflected in its very dense, old city centre, and gradual expansion outside the first city boundaries towards surrounding communities during 19th century. However, between 1960s and 1970s, due to an uncontrolled urban development, Brussels has suffered a haphazard urban development and redevelopment, consisting of neglecting the importance of the site context while introducing high-rise buildings into gentrified neighbourhoods. Its morphology is nowadays characterized by variety of present different forms of urban blocks, each one of them representing a cultural and architectural heritage. Urban blocks in Brussels strongly contribute to the heritage value of the city.

The city block is not first defined as an architectural form but as a set of plots attached together that acquire meaning because of their dialectic relation with the surrounding roads grid. The urban block is formed by the complex dialogue between the distribution of properties, the constructions and different types of public space.
It is also possible to conceive the city block as a package composed by an edge and an interior: the edge is defined by a succession of buildings built in the plots aligned to the street, both continuous or not. The buildings that form this edge don’t need to be homogeneous to be understood.

This second part of B³-RetroTool research project aimed to identify typology of city block and for each type to propose case studies and some methodological principles for sustainable retrofit. This part of the research has included four steps: definition of criteria for typological classification, data collection and mapping, analysis of case studies and proposition of methodological principles for sustainable retrofit.

2.1. Definition of criteria for typological classification

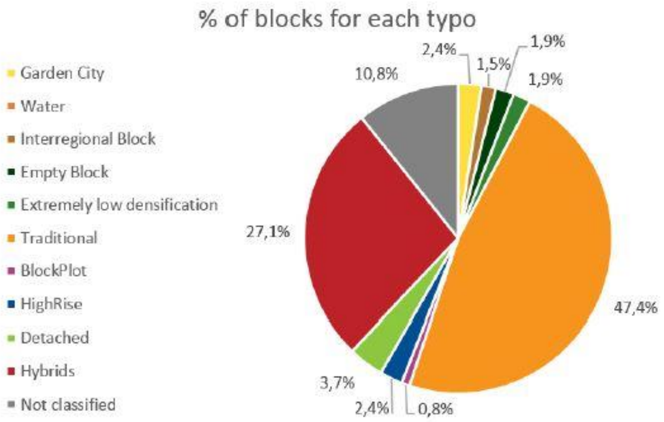
With the aim of characterising the different types of city blocks and to better understand their configuration, the authors have analysed the morphological evolution of Brussels to be able to deduce the 18 city block typologies. The indicators used for this classification are the following: area of the block, number of plots, average height, maximal height, height difference, building type and the built density. Nevertheless, two typologies have been gathered through literature review and web tools. One may find below the list and the definition of the 9 main blocks’ typologies:

- Garden City Blocks: these blocks appeared at the beginning of the XX century as a result of a ‘wild’ urbanization and as a response to the crisis of social housing. The garden city is characterized by a clear and low density structure with neighbourhoods morphologically differentiated. The building typologies are quite uniform and with low density and tension between the public and private space.
- Water City Blocks: this typology indicates all the blocks wherein water can be found. These blocks can be divided in three main types: blocks entirely filled in with water, blocks wherein the water represents an important part of it and blocks in which water can be found but does not represent a majority.
- Interregional and Housing City Blocks: City blocks provided by the UrbIS maps are not always located in one statistical sector. This observation is repeated in all partitions of Brussels (municipalities, neighborhoods and region). At the region level, the consequence is that several blocks are trimmed in two. Those blocks will provide wrong information about their total area but also about the other indicators because the cadastral matrix only gives data on the plots inside the BCR. The number of concerned blocks being rather high, gathering them through on-site checking seemed inappropriate. Moreover, a trimmed block with a consequent area could still give interesting information about himself and its inner components. On the other hand, some of the blocks inside the region have also a rather small area, approximately equal to the built surface of a house. In order to partially remove the smallest interregional blocks as well as the smallest blocks inside the region, a single condition on the area of the blocks have been set up.
- Empty City Blocks: this typology gathered all the blocks on which the footprint area is null. It represents mainly all the parks and forest on which no living construction can be found.
- Extremely Low Densification City-Blocks: this typology has been created to classify the lowest densified blocks. It represents mainly the parks which have a construction on their area or the large blocks with a few constructions on it. Paired with the Empty Blocks, it indicates all the parks and the lowest densified city blocks in Brussels.
- Traditional City Blocks: most of the blocks inside the Brussels’ region are entirely closed and composed of Brussels’ traditional houses such as; “Maison Bourgeoise”, “Maison de rapport”, “Maison Modeste” and so forth. This typology can be found in many places in Brussels and includes about 50 percent of the classified blocks. Additional information will allow re-classifying this typology in subcategories according the year of construction, the nature, the built density and the percentage of empty plots.
- Block-Plot City-Blocks: some of the city blocks inside Brussels contain only one plot on their total area. This specific situation can happen everywhere in Brussels for every type of constructions. Churches, houses, apartments’ buildings, observatory and so forth can be a Block-Plot city block.
- High-Rise City-Blocks: High-Rise buildings started to expand in the early 20 century, intensively after the first World-War. It became one of the basic elements of urbanization. This type of construction led to a new urban form, the open plane- «le plan libre». When blocks became to be built entirely with this type of construction, a new typology of blocks was born: the High-Rise Block. This typology breaks the current urban fabric of the city and modifies consistently its landscape. High-Rise blocks still present various types of blocks (Closed vs Open, Skyscrapers vs High-rise). Churches can be included in this typology. Indeed, their towers are often higher than 30m.

- Detached City-Blocks: this typology is relatively similar to the Garden-City Blocks. Blocks are open and their interior can largely be seen from the street. The Detached typology can be found mainly in the second ring, especially in the following municipality: Anderlecht, Watermael-Boitsfort and Woluwé St.Pierre
- Hybrid City-Blocks : this typology is due to the evolution of ancient city blocks that have suffered ulterior interventions. As a result it becomes the juxtaposition of several of the types defined above.

Type	City Blocks	Area [m²]	Built Density	Nb.Plots	Av.Height [m]	Max Height [m]	Delta Height	Building type
1	Interregional	<1000	-	-	-	-	-	-
2	Water		gathered through literature review and web tools					
3	Empty		0	-	-	-	-	-
4	Extremely Low Densification		<5%	>1	>0	-	-	-
5	Traditional		>30%	>1	>10	1<x<30	-	2 free facades
6	BlockPlot	>1000	-	1	>0	1<x<30	-	-
7	Detached		>10%	>1	<20	1<x<30	-	3/4 free facades
8	Garden City		gathered through literature review and web tools					
9	Highrise		-	>1	>10	>30	<10	no building types
10	Hybrid		Other indicators					

Figure 1: Blocks' indicators for the classification



Typology	Nb of blocks
Garden City	109
Water	0
Interregional Block	68
Empty Block	85
Extremely low densification	83
Traditional	2121
BlockPlot	38
HighRise	107
Detached	166
Hybrids	1214
Not classified	482
Total	4473

Figure 2: Percentage and amount of blocks for each typology

Figure 3: Urban location of of High-Rise City Blocks

Figure 4 : Urban Location of Detached City Block

2.2. Data collection and mapping

The data used in order to achieve the city blocks classification was mainly coming from the cadastral matrix of the residential stock and the UrbIS 2D and 3D maps. It allowed us to develop many indicators in a bottom-up approach. It enables to know which plot contained in the cadastral matrix was part of which block. Then, by aggregating the plot values contained in the same block, a new database show below was shaped:

	SURFACES				NATURE										
Block	Total Block Area [m²]	Footprint [m²]	Floorspace [m²]	Plots' quantity	RESIDENTIAL			NON RESIDENTIAL			EMPTY PLOT		Ground Occupancy	
					% Built Surface	% Plot	% Surfac	% Built Surface	% Plot	% Surfac	% Plot	% Surfac	% Built Density	Compactness
1	7231,515791	1809,002007	2282	16	58%	63%	54%	42%	19%	32%	19%	13%	25%	2,177684053
2	69684,63947	6436,327858	10879	34	99%	62%	61%	1%	9%	11%	29%	28%	9%	1,711137438
3	23648,60704	2641,297766	4891	10	100%	70%	79%	0%	0%	0%	30%	21%	11%	1,85174124
4	910829,7125	794,0216738	343	6	27%	33%	0%	73%	33%	2%	33%	98%	0%	1,574703638
5	72026,31279	2572,260487	3403	45	87%	24%	19%	13%	11%	2%	64%	79%	4%	1,513249923
6	2397,345365	379,1860946	985	8	100%	50%	65%	0%	13%	0%	38%	35%	16%	2,607747543
7	791,5232225	0	0	2	0%	0%	0%	0%	0%	0%	100%	100%	0%	0
8	15646,20251	2359,622857	3781	26	98%	77%	63%	2%	12%	5%	12%	33%	15%	1,62998937
9	114837,42	8727,761532	13643	36	90%	67%	60%	10%	14%	10%	19%	30%	8%	1,733895331
10	1487,521576	44,2970654	131	9	46%	11%	1%	54%	22%	2%	67%	97%	3%	6,487162875

Figure 5: Sample of the blocks' database part 1

	FACADES					Year of Construction												HEIGHT	HEIGHT	HEIGHT
Block	%A	%B	%C	% of Unknown Data	% OF DATA					1900 - 1950			1950 - 1990		<1850	nodata	Average Height [m]	Average Height in Levels [residential] [-]	Maximum height
1	19%	25%	6%	50%	50%	0%	##	##	0%	38%	13%	0%	13%	13%	0%	38%	12,26453846	0,9	14,851
2	0%	9%	44%	47%	53%	0%	3%	9%	0%	12%	##	12%	35%	15%	0%	38%	11,89183333	0,571428571	19,235
3	0%	0%	60%	40%	60%	0%	##	##	##	40%	0%	##	20%	10%	0%	30%	12,77628571	1	18,061
4	0%	0%	33%	67%	33%	0%	0%	0%	##	33%	0%	0%	0%	0%	0%	67%	9,4905	0	11,878
5	2%	7%	11%	80%	20%	4%	0%	7%	0%	7%	2%	7%	9%	4%	0%	76%	9,898125	0,363636364	12,985
6	0%	13%	38%	50%	50%	0%	0%	##	0%	13%	##	0%	25%	13%	0%	50%	8,6612	1	13,999
7	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0	0	0
8	42%	27%	4%	27%	73%	0%	##	##	8%	65%	4%	0%	4%	8%	0%	23%	9,58026087	0,65	13,686
9	0%	3%	53%	44%	56%	0%	0%	##	0%	14%	11%	6%	17%	36%	0%	33%	10,79572414	0,791666667	19,511
10	0%	0%	11%	89%	11%	0%	0%	##	0%	11%	0%	0%	0%	0%	0%	89%	8,908666667	1	12,698

Figure 6: Sample of the blocks' database part 2

The following indicators were developed in this data base and mapped with ArcGIS:

- Morphology: total area of the block, footprint, built density , most recurring building type in the block (2-3-4 free facades) , average height , maximal height, slopes and orientation of roofs and surfaces;
- Urban function: residential, commercial, industrial, administrative, empty plots;
- Heritage value: date of the construction;
- Energy consumption
- Environment: permeable areas and non permeable areas.

2.3. Analysis of case studies

This typological classification enables the observation of the most recurring blocks' typologies in the Brussels region. In order to develop methodological principles which could be applied on a larger part of the blocks' stock in Brussels, it was decided to work on the most numerous typologies. The three larger typologies are the ***traditional blocks*** (closed perimeter), the ***hybrid traditional detached blocks*** (mixing bonded buildings with openings on the interior of the block) and ***the hybrid***

traditional high-rise blocks (mixing bonded buildings with buildings of more than 30m). Together, they represent approximately 65 percent of the blocks' stock.

One block of each of these typologies was chosen as case study. A second set of indicators were used: the built density, the most recurring function, the year of construction, the percentage of empty plots, the average height, the number of plots and the area. Each of these indicators was subdivided in categories. The most numerous categories in each indicator were retained and the block corresponding to these categories was our case studies.

Each case study will be analyzed as follow:

- <u>General description:</u> localization (with pictures), surrounding streets (with pictures), EDRLR area (Y/N), neighborhood contract (Y/N), particularities in the blocks, graphical indicators of urban integration;
- <u>Morphological, typological and functional indicators:</u> area, footprint, built density, residential floor space, number of plots, average and maximal height, years of construction, building types, share of functions, additional information (comparison of the block with its typology);
- <u>Energetic and environmental indicators:</u> water, gas and electricity consumption (WP1), distance from a green space, surfaces seen from satellites' view;
- <u>Additional information:</u> share of housing typologies.

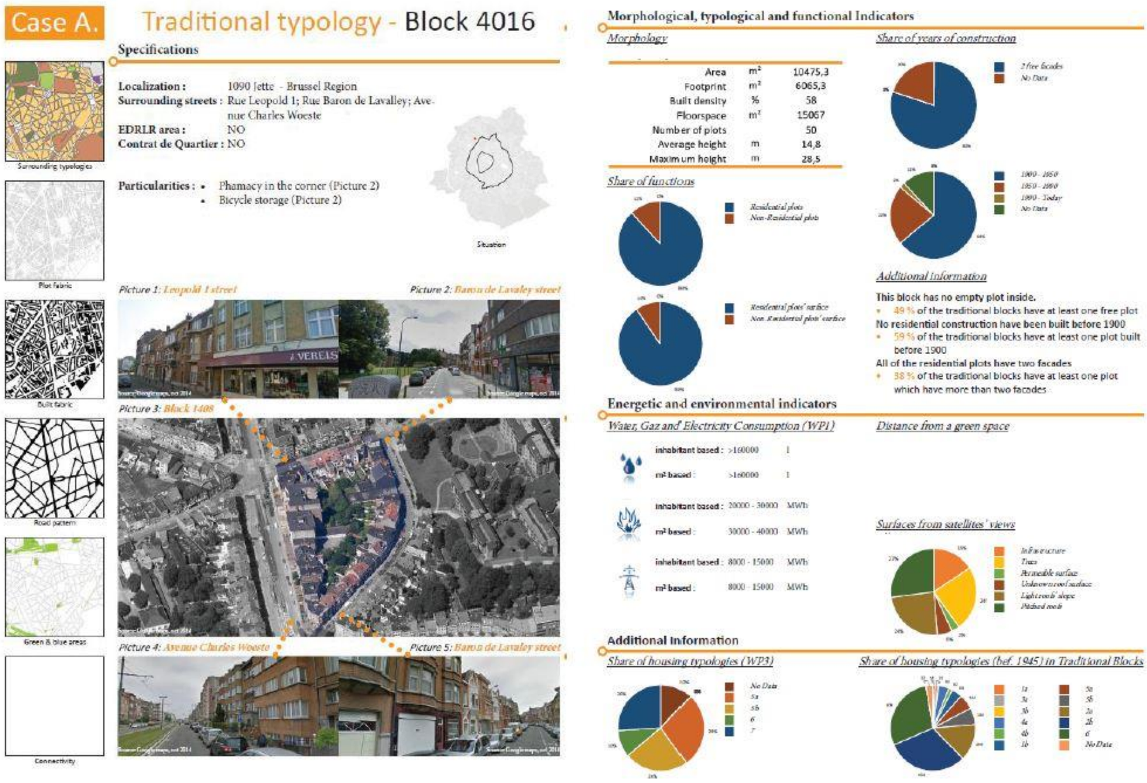


Figure 7: Part of the analysis of the traditional case study

3. Evaluation of the Brussels dwelling stock

The dwellings stock built before 1945 in Brussels has a great heritage value for Brussels Capital Region and represents 60% of the built environment the latter of which is responsible for 62% of the region's energy consumption.

The goal of this part was to bring further knowledge on the specific building stock of Brussels by a bottom-up analysis based on the characterization of building typologies.
This part of the research focused only on the dwelling stock built before 1945 for three main reasons. First, this is the largest share of the Brussels dwellings stock (60%). Secondly different types of dwelling could easily be identified. Thirdly, this dwellings stock requires urgent improvements in terms of energy performance and inhabitancy.
This part of research included five steps: definition of dwelling typology, repartition and urban situation of the dwelling types, assessment of potential improvements of building stock, analysis of case studies and proposition of methodological principles for sustainable retrofit.

3.1. Definition of dwelling typology

The study of the dwelling typology built before 1945 was established from the late 17th century for several reasons. First, Brussels dwelling stock built before 1695 consisted mainly of wooden buildings and thatched roof. This type of buildings will gradually be prohibited for reasons of fire protection but the bombing of Brussels by French troops definitely ended wooden building. Secondly, the building permit and the various regulations standardizing construction are emerging from the mid-17th century to generalize the 18th century.

Dwelling types were defined according to morphological and urban development in Brussels and its suburbs but also based on changing patterns of living in Brussels as well as construction methods and materials used. Three periods of urban development have been identified. Those periods are at the origin of different dwelling types:

- From 1700 to 1890: urban development in Brussels, the first great work of urbanization and development of capital. During this period, single-family housing dominates the Brussels landscape with dwelling type “maison bourgeoise” and its variants.
- From 1890 to 1914: transition period, where architecture and urbanism hesitates between nostalgia for the past and a desire for modernity. Victor Horta, with the construction of the Hotel Tassel in 1893 launched a new trend: the “Art Nouveau” will influence future architecture, construction techniques and urbanism even if it is still mainly « maisons bourgeoises » and « hôtels de maître ».
- From 1920 to 1945: from 1920, many changes occur in both in the urban planning of Brussels and in the types and styles of accommodation.

Regarding the types of dwelling, the authors have distinguished two key periods:

- From 1700 to 1914 : predominance of individual housing (small, bourgeois and aristocratic), whose spatial organization will be based on the spatial organization of the “maison bourgeoise”;
- From 1920 to 1940 : emergence of worker house in the garden cities and apartment building (building modest, standard and / or high status) that takes his real development after 1930

A. Dwelling typology – from 1700 to 1914

The single family row house was the most common form of dwelling in Brussels until 1914. It is rare to see apartment buildings before First World War except a few tries on the boulevards in the centre of Brussels. For this period, there are three main types of dwelling:

- Modest or worker row houses mostly located in the popular and industrial districts, in narrow streets or impasses and in the Brussels periphery (late 19th century);

- Maisons bourgeoises located in residential districts of the pentagon, mainly in the top of the city, along the main avenues and the extension areas. The spatial organization of the “maison bourgeoise” has also changed from 1700 to 1914. Therefore, we have defined three subtypes: maison bourgeoise built before 1830, neoclassical maison bourgeoise, built between 1830 and 1870 and maison bourgeoise bel étage – built after 1870;
- Hôtels de maître built for the upper bourgeoisie and aristocracy, after 1830, along large avenues and in some districts extensions.

In addition to these three types, the houses with shop (maison de commerce) and apartment houses (maison de rapport) which are variations of the maison bourgeoise must be added to the study. Those types of dwelling will also be set up on the corner plots and near train stations and infrastructure.

B. Dwelling typology – from 1920 to 1940

The beginning of the First World War, in 1914, traditionally marks the end of a period both in Western Europe in Brussels. Mentalities as techniques evolve significantly. The car is spreading, domesticity disappears, the role and place of women change. These changes have an impact on the spatial design of the habitat and the urbanization of the city.

From 1920, many changes occur in both the urban planning of Brussels and in the types and styles of accommodation whether individual row house remains predominant. Spatial design of dwellings will also be influenced by Art Deco and Modern Movement. Both two movements believe that architecture should be a rational and practical architecture, and facilities meet the requirements of daily life, but must also be attractive and harmonious.
Brussels city extends widely. Peripheral suburbs strongly denser and there appears a distinction between place of residence and place of work. The arrival and spread of the automobile will substantially change the relationship to public space and also induces changes in the individual dwelling (presence of a surface or garage parking).

The 20th century saw the emergence of new ways of living, both for the bourgeoisie to the working population. Garden cities are built for the workers at the extremities of the city. By 1930, after the financial crisis of 1929, apartment buildings for middle class - back in town - are growing in Brussels.

For this period, we can distinguish the following types of dwelling:

- Maison bourgeoise – evolution: built in still less urbanized areas in close proximity to Brussels (Uccle, Boitsfort Auderghem, Ganshoren, Anderlecht ...), thereby accelerating urbanization of the second belt of suburbs. The spatial organization of the “maison bourgeoise – evolution” will be influenced first by the different architectural styles (art nouveau, art deco, modernism) and secondly by the emergence of new technologies, new materials (concrete, steel) and constructive processes but also by the emergence of the car. The garage will generalize, either at the ground floor or in the basement with the cellars.
- Worker row house in garden-city: built on the periphery of Brussels from 1900 to 1930. They show mainly two types of houses: "English cottage" house and modernist, cubist and functional house. These workers' houses are mainly terraced houses, with small dimensions and two or three façades according to their implantation.

- Apartment building: the period between the two world wars saw a rising number of apartment buildings in the Brussels-Capital Region. At this time, Brussels citizens, fervent supporters of individual dwelling, are still reluctant to this new type of dwelling together. Various technical and socio-economic factors, however, will promote and encourage the construction and adoption of this type of habitat by all layers of the population, including the bourgeoisie. Very variable, the size of this type of dwelling goes from small apartment building with three to four levels to skyscrapers of eighteen floors. In terms of finishing, there was both buildings with a high level of comfort and luxury (Residence Palace) and social housing apartments with very simple amenities. In addition, some buildings have several functions coexisting: homes, offices, shops, theaters and cinemas. The diversity is also expressed in aesthetic terms: Beaux-Arts, Art Deco or modernist buildings. Two subtypes have been considered: the modest or social apartment building and the standard apartment building.

  The standard apartment building, built especially for the bourgeoisie, must be viewed as a collection of autonomous, spacious and well equipped accommodation: lift, intercom, garbage disposal, hoists and fitted kitchen. These terraced buildings are constructed on the alignment of existing buildings, in the bourgeois extension districts of Brussels.

C. *Description of each dwelling type – methodology*

The set of dwelling types has been studied according to the description given below:

- General description : situation / localization, spatial organization, inner circulation and staircase, building systems and materials, roof and building materials, façades and building materials
- Main characteristics: relation to the public space and street, size of the plot, size of the building (volume, number of level, number of division, annexes…)
- Alternatives (if they exist)

3.2. The building stock reparation and localization

Based on the precise description of each dwelling type, a simplified characterisation has been proposed to fit the data given in the cadastral matrix and to associate each lot to one type. As the figure here under shows, the characterisation is limited to three factors: date of construction, floor area, number of dwellings per building. The following graphs show the numerical distribution of each type (type "-" is the lot that did not correspond to any other types). There is a total of 159825 buildings and 498819 dwellings registered in the cadastral matrix (1.1.2012)

Type	TYPES BATIMENT B^3-RetroTool	avant 1850	1850-1874	1875-1899	1900-1918	1919-1930	1931-1945	Surf utile / Bat	Nb log / Bat	Surf/Log
0	Non applicable								0 ou 999	< 8
1a	Maison bourgeoise d'avant 1850							120-350		
1b	Maison bourgeoise type leopoldien (néoclassique)							120-350		
2a	Maison bourgeoise avec bel étage (1 logement)							120-350	= 1	
2b	Maison bourgeoise avec bel étage (> 1 logement)							120-350	> 1	
3a	Hotel de maître ou hôtel particulier							351-1000	<= 4	
3b	Maison de rapport							351-1000	> 4	
4a	Maison modeste d'avant 1919							25-119		
4b	Maison modeste après 1918 (dont cité-jardin)							25-119		
5a	Maison bourgeoise - Evolution (1 logement)							120-350	= 1	
5b	Maison bourgeoise - Evolution (> 1 logement)							120-350	> 1	
6	Immeuble à appartement							>350		
7	Après 1945									

Figure 8: dwelling types repartition – characterisation factors

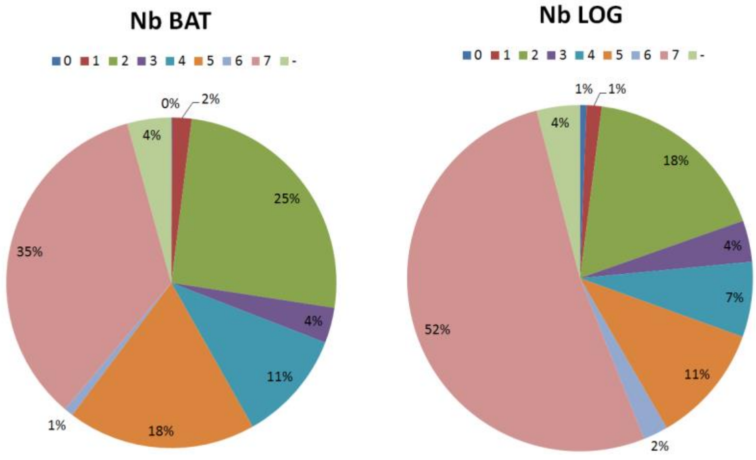


Figure 9: dwelling type's repartition – amount of buildings and amount of dwellings

Moreover, using ArcGIS software, the resulting database can be used to analyse spatial distribution of each type. The left map hereunder shows that this type of building was mainly built close beyond the first belt (former fortifications).
On the right, the map shows that after 1918 the buildings corresponding to the evolution of this type (type 5 called "Maison bourgoise – Evolution"), are built further out the centre, beyond the second belt. This structured database will be will be used to support the analysis on larger scale as building blocks and neighbourhoods (bottom-up analysis).

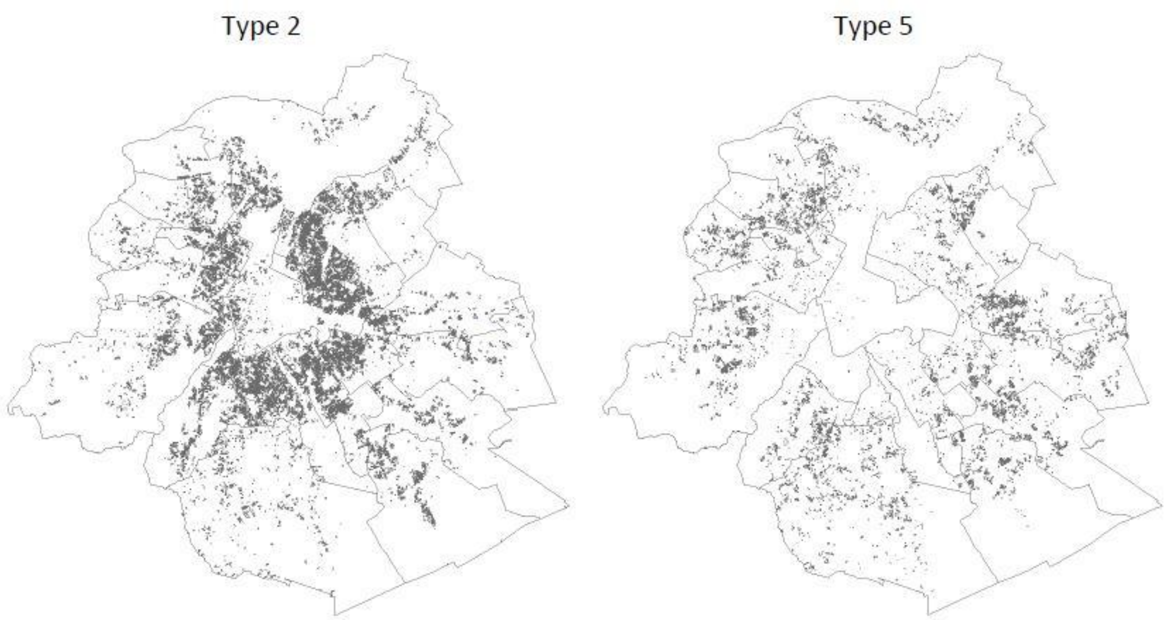


Figure 10: Urban localization of dwelling types 2 and 5

3.3. Analysis of case studies

For each type of dwelling, the authors have then searched for a case study sufficiently representative. Maximum information and plans of the initial situation were indispensable to understand their specificities.

With this objective, the authors have consulted various databases and information sources: Database BATEX of Brussels Environment, Inventory database of IrisMonument, Centre International pour la Ville, l'Architecture et le Paysage (CIVA) and AAM libraires, archiving services of various Brussels municipalities and contacts with various architects.

Each case study has been analysed as follow:

- General description: address, situation and location in relation with various data (green spaces, mobility…), date of construction, architectural style of the façade, renovation works and date;
- Main characteristics: disposition in relation to the road, size of the plot, size of the building (volume, number of level, number of division, annexes…), main architectural characteristics and outdoor spaces (garden, court, area in front of the road…);
- Description of the building envelop: building system (structure and building materials), roof (shape, structure, building materials, eaves), façades (size, building materials, windows, ornaments and decorations, …) and frames;
- Description of interior layout : basement, ground-floor or level « bel étage » and others levels.
- Description of equipment (if available): heating system, hot water production, draining system, ventilation system, presence of rainwater tank, presence of septic tank

The set of collected information is presented as a descriptive sheet and could be downloaded from the assessment tool.

Figure 11: Part of the analysis of the case study for dwelling type 2

Figure 12: Pictures of "neoclassical maison bourgeoise", "maison bourgeoise bel étage", "hôtel de maître", apartement house, evolution of maison bourgeoise 1, evolution of maison bourgeoise 2, modest row house in citygarden, standart apartement building and social apartement building.

3.4. <u>Assessment of potential improvements of building stock</u>

Based on the description of each dwelling type, various scenarios of retrofitting were proposed. They focused mainly on improving the energy performance of each dwelling type but also on creating opportunities for dwelling densification, function diversity and inhabitancy improvement. Scenarios proposed for each dwelling type will then be applied to the specific case study and assessed according to three criterias (heritage value, energy and environmental impact) and compared with the initial situation.

A. Climatic data of Brussels Capitale Region

The reference Belgian external climate is a relatively cold, humid and rainy temperate climate. The data presented below, were measured by the Belgian Weather Royal Institute in Uccle (Longitude: 4.36°E, Latitude: 50.80°N; Altitude 100 m): average temperature (9.9°C), average relative humidity of the air (80%), average wind speed and orientation (3.6 m/s, south-west), average global solar radiation (108 W/m² with min:0 - max 889) and average precipitation (930 mm per year).

B. Assessment indicators and criteria

Each assessment axe contains a series of indicators presented in the table below. All indicators will be analyzed and assessed relative value compared to extreme values and values distribution of chosen category. Results can be expressed using different units, depending on the indicator (i.e. per building, per dwelling, per person, per m2…). Heritage value criteria, indicators and sub indicators were gathered in a synthesis document with a distinction of each dwelling type.

General data	Energy	Heritage value	Environmental Impact
Plot area Built area Floor area Number of building Number of inhabitant	Energy load for heating Energy load for electric devices Energy load for hot water production Embodied energy of materials Renewable energy production	Building quality Coherence quality Preservation quality Resilience quality	Bill of materials Bill of CO_2 emission Water use Permeable area Biodiversity index

Figure 13 : Assessment criteria (Energy – Heritage value – Environmental Impact)

3.5. Methodological principles for sustainable retrofit

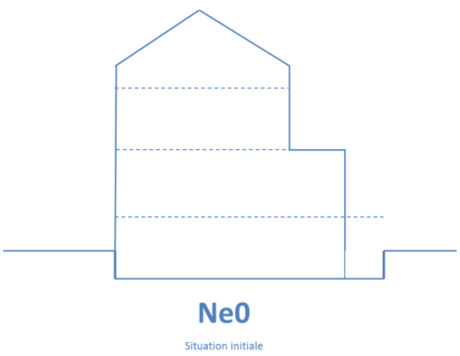
Various scenarios were proposed with the objective to improve significantly the energy performance of the dwellings. Those scenarios focused first on the envelope and then on the technical services. Scenarios on technical services improvement are proposed according to the energy performance achieved by the envelope and the building occupation. As example, mechanical ventilation with heat recovery is only proposed for the case where the envelope performance achieves the standard “very low energy consumption”.

A. Envelope retrofitting scenarios “Ne” (for dwelling types 1,2,5)

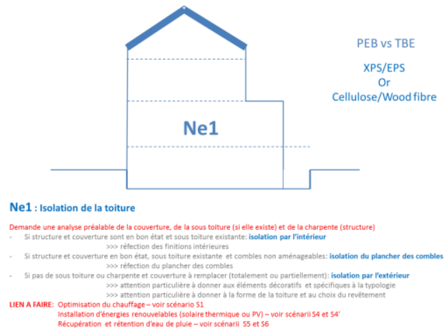
The envelope retrofitting scenarios were defined based on a trend analysis performed on the renovation of housing awarded at Exemplary Buildings initiated by Brussels Environment. They are proposed by phases, knowing that today, only few Brussels owners can afford all of the retrofitting works in one phase. The retrofitting steps are proposed in a hierarchical manner, taking into account the state of the dwelling, the influence on the energy performance and the extent of work required. The authors have considered two performances for the envelope retrofitting scenarios (current EPB regulation and the “passivehaus” standard) and two types of insulation materials (EPS or XPS> <Wood or cellulose fibers)

As an example, the envelope retrofitting scenarios for the “maison bourgeoise” (Type 2 and 5) are the following:

Initial situation



Ne 1: *Roof insulation*

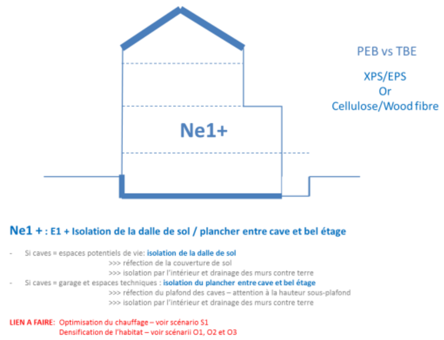


In the web tool, the user can choose between:

- *U-value of 0,24 W/m^2 or 0,15 W/m^2;*
- *Extruded polystyrene (XPS) or cellulose insulation.*

Ne1 + *: Roof insulation + slab floor insulation*

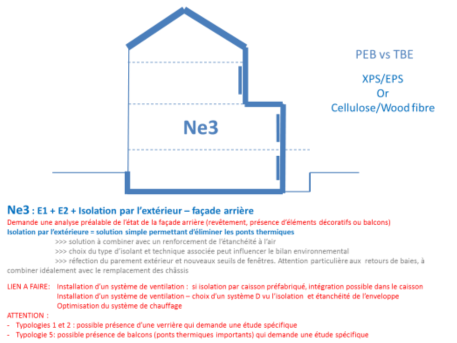
This envelope scenario has not been considered by the web tool because the Energy Metric version does not allow to model yet.



Ne2: *Ne1 + Frame replacement (back cover façade)*

In the web tool, the frame and the glazing are replaced at the same time. The user can choose between: double glazing or triple glazing and wooden frame or aluminium frame.

Ne3 : *Roof insulation + Frame replacement (back cover façade) + back cover façade insulation*

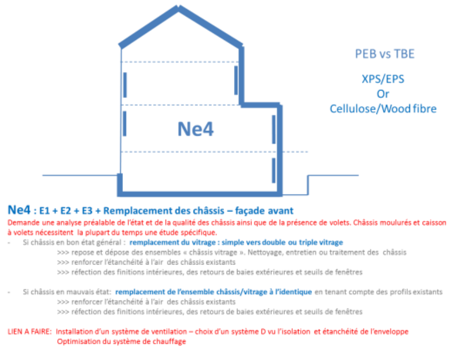


In the web tool, this façade is considered to be 60% of exterior walls. The user can choose between:

- *U-value of 0,24 W/m2 or 0,15 W/m2;*
- *Expanded polystyrene (EPS) or wood-fibre insulation.*

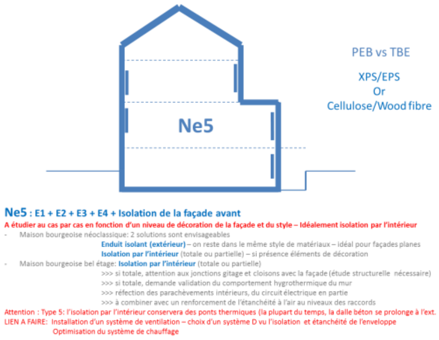
Ne4 : *Roof insulation + Frame replacement (back cover façade) + back cover façade insulation + Glazing and/or frame replacement (main façade)*

The main façade being highly ornamented and the frame strong, the replacement of the frame and/or glazing therefore requires a detailed study.
In the web tool, the frame and the glazing are replaced at the same time. The user can choose between double glazing or triple glazing and wooden frame or aluminium frame.



Ne5: *Roof insulation + Frame replacement (back cover façade) + Back cover façade insulation + Glazing and/or frame replacement (main façade) + Main façade insulation*

The main façade being highly ornamented, insulation from outside is often not possible. Inside insulation means to pay attention to thermal bridges and hygrothermal properties of assemblies (especially in case of timber framed floors).



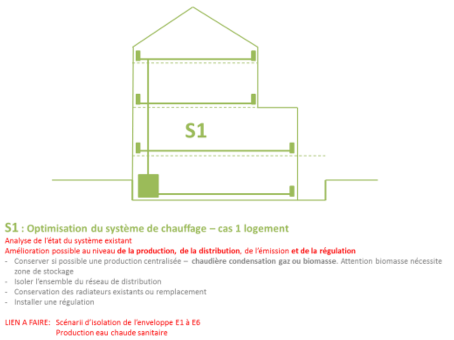
In the web tool, this façade is considered to be 40% of exterior walls. The user can choose between:

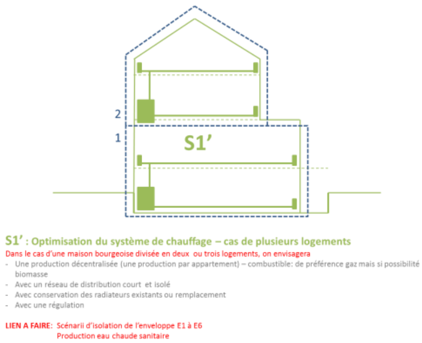
- *U-value of 0,24 W/m2 or 0,15 W/m2;*
- *Extruded polystyrene (XPS) or cellulose insulation.*

B. *Equipment scenarios Ns*

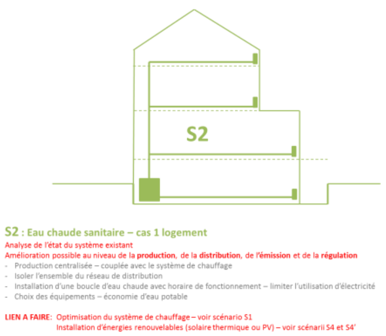
Those scenarios are proposed taking into account the performance achieved by the envelope, the existing technical services and the possible densification of the dwelling. The scenarios propose improvement strategies for existing techniques but also for integration of ventilation systems, renewable energy systems (solar thermal and PV), rainwater infiltration systems and acoustic insulation (in case of dwelling densification). As an example, the technical services retrofitting scenarios for the "maison bourgeoise – type 1/2" are the following:

The equipment scenarios proposed are the following:





Figures 14: Ns1: Optimisation of heating system- one or two dwellings



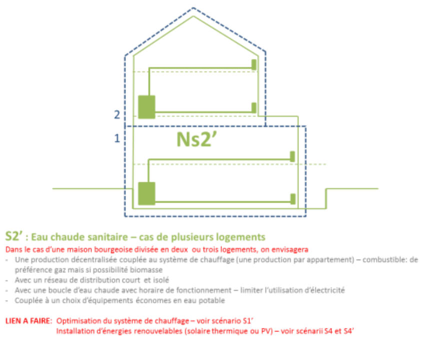


Figure 15: Ns2 : Optimisation of hot water production – one or two dwellings

Figure 16: Ns3 : Ventilation system – system C or system D

In the web tool B³RetroTool, all buildings are considered to have, in initial state:

- *A centralised heating system (μ=65%)*
- *Hot water supply (μ=65%)*
- *Ventilation system of type "A"*
- *Air tightness of 12 m3/hm2*

In addition, the web-tool user can choose to improve his equipment with the combined scenarios "improving the equipment – Step 1",

- *Heating system (μ=80%)*
- *Hot water supply (μ=80%)*
- *Ventilation system of type "C"*
- *Air tightness of 6 m3/hm2*

The user can also choose to improve more deeply his equipment with "improving the equipment – Step 2", but this step is only available if he chose envelope scenario n°3 or more for type 2 and 5 and n°2 or more for all other types:

- *Heating system (μ=90%)*
- *Hot water supply (μ=90%)*
- *Ventilation system of type "D"*
- *Air tightness of 1 m3/hm2*

C. Solar heating scenarios Nf

Installation of thermal solar system (decentralized system – 1/dwelling) must be thought according to the orientation and surface area of the roof and combined with the roof insulation (E1) and improvement of hot water and heating production (S2).

Installation of thermal solar panel on the front façade could be sometimes difficult in terms of heritage value.

In the web tool, the user can choose to install solar heating system: 5 m2 or 15 m2.

Photovoltaic scenarios Npv

Installation of PV system (decentralized system – 1/dwelling) must be thought according to the orientation and surface area of the roof and combined with the roof insulation (E1) and new electrical installation. Installation of PV panel on the front façade could be difficult in terms of heritage value.

In the web tool, the user can choose to install photovoltaic panels: 15 m2 or 30 m2.

D. Recovery of rainwater scenarios – Et

Most of time, the types « maison bourgeoise 1 / 2 » are equipped with a rainwater tank.

In the web tool, the user can choose to install a system of rainwater recovery: 1. only from the back-side roof (60% of roof surface -> 45% of economy in water consumption), 2. or from all roof surfaces (100% of roof surface -> 70% of economy in water consumption).

The economy of water consumption is assumed to be shared equally between all dwellings of the building (if more than one).

E. Infiltration of rainwater scenarios

Most of time, the types « maison bourgeoise 1 / 2 » have a good-size garden and sometimes presented in front of the house a specific area treated as garden and/or parking.

Garden at the back of the house and the specific area in front of the house could be an opportunity to create areas of retention and infiltration of rainwater. This retention and infiltration scenario could be combined and thought with the rainwater recovery.

In the web tool, the user can choose to infiltrate rainwater: 1. 50% of rainwater falling on ground floor is infiltrated; 2. 100% of rainwater falling on the ground is infiltrated; and 3. 100% of rainwater falling on both the ground and the roofs is infiltrated. The third choice can only be made is no rainwater is recovered for inside uses. The results of these scenarios are :

- The ratio between the area of the building plot compared to total infiltration surface;
- A value for the biodiversity index assuming that permeable surface can host vegetation

F. Densification scenarios

The densification retrofitting scenarios analyse the possible way to increase the number of dwelling, especially into the "maison bourgeoise" characterized by a very large surface area available (up to 400 m²). Specific scenarios were also proposed for:apartment buildings: and modest house in city garden:

The densification retrofitting scenarios for the "maison bourgeoise type 1 – 2 " are presented below:

Initial situation

The type "Maison bourgoise" sheltered only one single family and was divided into different spaces: reception areas, residential areas and service areas. Based on a same construction system and spatial organization, the type "maison bourgeoise" presents very different living areas according to the number of rooms and the number of floors.

Densification scenarios that were considered in the study are:

- If surface area < 150 m² : only one dwelling/building
- If surface area > 150m²: 3 scenarios are possible: O1 (building sheltered on dwelling), O2 (building divided into two dwellings) and O3 (building divided into three dwellings)

In the web tool, the user can choose to increase initial number of dwellings for type 2, 3a and 5. Type 2a and 5a can have 1 (initial value) or 2 dwellings; Type 2b, 2c, 5b, 5c and 5d can have 1 (initial value), 2 or 3 dwellings; Type 3a can have 1 (initial value), 3 or 5 dwellings. The number of dwellings cannot be modified for the other types. The default value is 8 dwellings for type 3b and 6 dwellings for type 6, based on the average number of dwelling of these types in cadastral matrix. The default value for all other types is 1 dwelling.

All those scenarios have been combined (as exemple: Ne + Ns + O) by the web tool.

RESEARCH RESULTS: PRE-ASSESSMENT TOOL

The tool developed is the result or the synthesis of the research. The tool focuses on Brussels Capital Region through 5 scales of intervention (region, municipality, neighbourhood, city block and buildings) including and combining criteria on energy performances, environmental impacts and heritage value.

The tool provides to potential user comparative data of existing real estate elements at each scale (city, municipality, neighbourhood, city-block and building). It offers comparative values for aspects related to energy, environment and heritage and it allows making prospective of evolution according to retrofitting scenarios defined by each potential user/stakeholder.

Figure 17: web interface – city

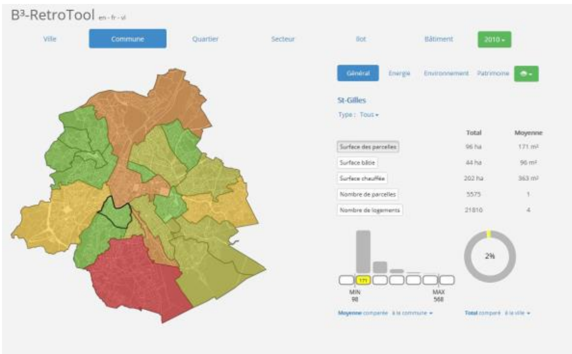


Figure 18 : web interface – municipality

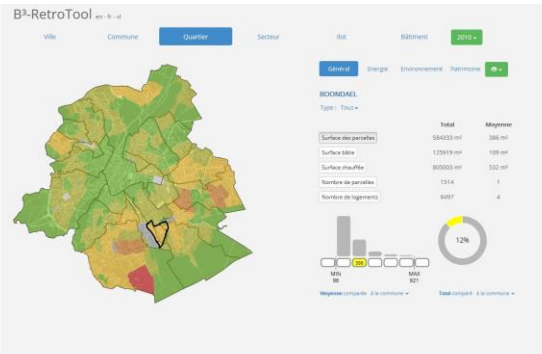


Figure 19 : web interface – neighbourhood

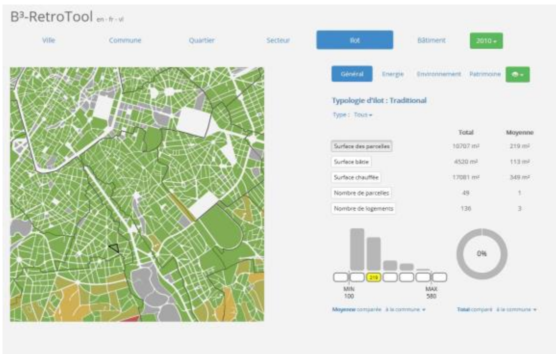


Figure 20: web interface - cityblocks

1. Web interface

The tool will be available on-line in 3 languages: French, Flemish and English.

To be free, light and fast, a series of maps in Scalable Vector Graphics (.svg) format connected to a simple MySQL database were used. User interface is coded in html using JavaScript library D3.JS.

First, a home page will present the objectives, hypotheses, research and founding partners of this work. The user will then enter the tool by choosing to analyse existing state (in 2010) of dwellings of Brussels Capital Region at one of the five different scales proposed: City, Municipality, Neighbourhood, City Block and Building. All indicators used in this research will be available at each scale: General data, Energy use, Environmental impact and Heritage value.

At the scale of Buildings, the user can select one building plot and according to the information provided by the tool (type of dwelling, built-up area ...) choose a combination of retrofitting scenarios and directly get a result for each criterion (energy performance, environmental impact and heritage value). The user could make this operation for just one or several building plots. This type of operation could also be done at the scale of City Blocks.

The user has also the possibility to select, at the scale of neighbourhood and municipality, all building plots corresponding to a dwelling type and to choose for those building plots a mix of retrofitting scenarios and directly get a result at the scale of the neighbourhood and/or municipality.

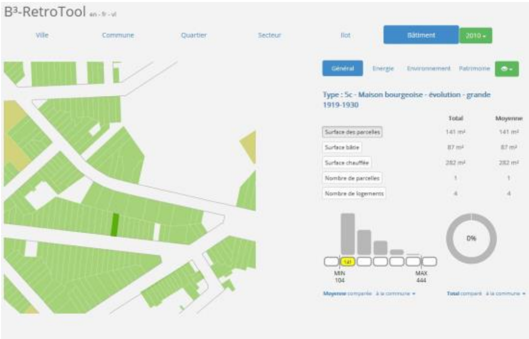


Figure 21: web interface – dwelling/buildings

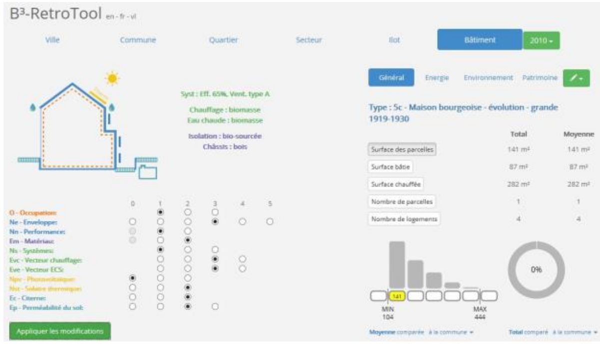


Figure 22: selection of retrofitting scenarios

The potential user can also decide to assess the evolution of dwelling stock through the definition of its state in 2020, 2030, 2040 and 2050. The user can thus define new scenarios of evolution. Default scenarios will be proposed.

2. Database

The structure of the database (MySQL) allows new data to be considered anytime allowing an easy update of the tool. It contains three main tables: TYPES, BASE, TEMP. A set of table, named TDxx, are used to gather reference information at all scales. Other tables are used (to change the language, to change the units…).

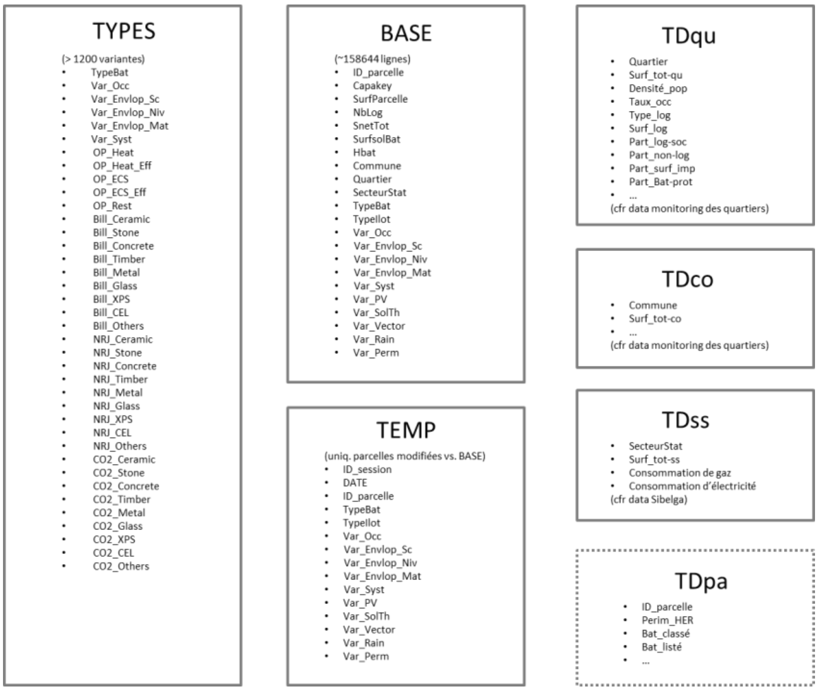


Figure 23: structure of the web tool database

The table "Types" contains the results obtained with Energy Metric software [6] for each combination of scenarios of each type of building (more than 1200 variants).

The table "Base" contains the information associated to each dwelling plot (158644 plots). Depending on the type of building and the scenarios chosen, a value is generated for each indicator based on information of table "Type" or other information (i.e. for indicator such as renewable energy production, water use, permeable area and biodiversity index).

The table "Temp" contains all information associated to plot state in 2020, 2030, 2040 or 2050. Only the plot that has been modified compared to its state in 2010 is taken into account in this table. This table must be saved by the user if he wants to access it later on. The table "TDxx" ("TD" stands for "Top Down") contains useful reference information at different scales (Monitoring des Quartiers, Brugis, ESE2001, EQ2007, Sibelga, Bilan ICEDD…).

3. Displayed results

Results for all indicators are presented graphically (see Fig. XX). A map shows an indication of the spatial distribution of the results for selected criteria. On another graph, the selected element is ranked (horizontal scale) compared to extreme values of a larger group of elements (e.g. a specific municipality is, by default, compared to other municipalities). For each indicator, the mean value or the total value for this element can be presented (except when selecting a single plot). If needed, more than one element can be selected, and the group of elements used in the comparison can be adapted (e.g. the plots of a whole street can be selected and chosen indicator can be compared to mean value of a specific municipality). Vertically, the user can read the distribution of values among the group used for comparison. The figure here under gives an example of graphical presentation. The results can be expressed in different units (e.g. per m², per person, per dwelling, per building…). Bill of material quantities can be expressed in m³ or kg. When an indicator can be assessed based on reference values or values based on a top-down approach (from table "TDxx"), the user can choose to display those values in parallel.

Other graphical representations is available to the user: evolution of a specific indicator from 2010 to 2050, comparing different scenarios (see http://130.104.235.5/epeeh/ > “accès privé” (Login and password: "bxl-retrofit") > “outil d’analyse prospectif”); global overview of building stock (see example http://bl.ocks.org/kerryrodden/477c1bfb081b783f80ad and http://bost.ocks.org/mike/treemap/); modify retrofitting scenario for an element or a group of element at any scale…

CONCLUSION

The main outcome of the research is a pre-assessment tool supporting the retrofitting of Brussels in an integrated multi-criteria and multi-scale approach. This pre-assessment tool provides:

- A clear vision and comprehension of urban metabolism on different scales: city, municipality and neighbourhood;
- A clear identification of priority urban areas and city-blocks requiring an urgent retrofitting as well as a clear identification of different types of dwellings built before 1945 and their buildings specificities.
- Various retrofitting principles proposed for each type of dwelling and city-block and assessed through 3 axes (Energy, Environment and Heritage Value)
- Prospective scenarios, in the longer term, for each component of the Region (city, district, city-block, and building)

Although pre-assessment tool B³-RetroTool offers a great potential of use for the retrofitting sector in the Brussels Capital Region, it is still a BETA version. An additional year of work is foreseen in order to improve the usability of the software by different type of stakeholders (inhabitants, municipalities, administrations, real estate companies, architects, etc) and to increase the range of the results provided by this tool. The final version will be launched in December 2015.

ACKNOWLEDGMENTS

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