"SUSTAINABLE RETROFITTING OF DWELLINGS IN BRUSSELS CAPITAL REGION: FIVE SCENARIOS OF EVOLUTION USING A MULTI-SCALE AND -CRITERIA PRE-ASSESSMENT TOOL"

Evrard, Arnaud ; Trachte, Sophie ; Hermand, Cédric ; Bouillard, Philpppe ; De Herde, André

ABSTRACT

In the next decades, most of the energy consumption of the building sector in Europe will be due to the buildings that exist today. The present paper presents the first results obtained by a web-based tool developed to enable a clear visualisation of existing dwelling stock in Brussels Capital Region and to help major stakeholders and public institutions of the region to define their strategies to retrofit the dwellings built before 1945. The tool is structured with six different scales and the characterisation of building stock is based on a set of criteria focused on three main topics: energy, environment and heritage value. Existing dwellings are grouped in seven different types and each type can be retrofitted in a specific manner (envelope, systems and number of dwellings per building). This paper presents and compares five scenarios of evolution of the dwelling stock. This tool can only be used to analyse Brussels Capital Region for the moment, but the methodology can be applied to other regions in the world. Enlarging the scope of this tool will help to meet the environmental, social and economic challenges of the contemporary world and to foster the transition of building sector towards a sustainable development.

CITE THIS VERSION

Evrard, Arnaud ; Trachte, Sophie ; Hermand, Cédric ; Bouillard, Philpppe ; De Herde, André. *SUSTAINABLE RETROFITTING OF DWELLINGS IN BRUSSELS CAPITAL REGION: FIVE SCENARIOS OF EVOLUTION USING A MULTI-SCALE AND -CRITERIA PRE-ASSESSMENT TOOL.*PLEA 2016 - 32th International Conference on Passive and Low Energy Architecture. Cities, Buildings, People: Towards Regenerative Environments (Los Angeles, du 11/07/2016 au 13/07/2016). In: Pablo La Roche, Marc Schiler, *PLEA 2016 - Proceedings of the 32nd International Conference on Passive and Low Energy Architecture*, 2016, p.452-457
http://hdl.handle.net/2078.1/175047

SUSTAINABLE RETROFITTING OF DWELLINGS IN BRUSSELS CAPITAL REGION:
FIVE SCENARIOS OF EVOLUTION USING A MULTI-SCALE AND MULTI-CRITERIA PRE-ASSESSMENT TOOL

Arnaud Evrard[1], Sophie Trachte[1], Cédric Hermand[1], Philippe Bouillard[2], André De Herde[1]

[1]Architecture et Climat, UCL, Louvain-la-Neuve, Belgium
[2]BATir, ULB, Brussels, Belgium

ABSTRACT: In the next decades, most of the energy consumption of the building sector in Europe will be due to the buildings that exist today. The present paper presents the first results obtained by a web-based tool developed to enable a clear visualisation of existing dwelling stock in Brussels Capital Region and to help major stakeholders and public institutions of the region to define their strategies to retrofit the dwellings built before 1945. The tool is structured with six different scales and the characterisation of building stock is based on a set of criteria focused on three main topics: energy, environment and heritage value. Existing dwellings are grouped in seven different types and each type can be retrofitted in a specific manner (envelope, systems and number of dwellings per building). This paper presents and compares five scenarios of evolution of the dwelling stock. This tool can only be used to analyse Brussels Capital Region for the moment, but the methodology can be applied to other regions in the world. Enlarging the scope of this tool will help to meet the environmental, social and economic challenges of the contemporary world and to foster the transition of building sector towards a sustainable development.
Keywords: tool, existing dwelling stock, energy, environment, heritage value, scenario of evolution

INTRODUCTION

B³-RetroTool aims to offer a new vision of Brussels Capital region (BCR) by approaching the retrofitting of the city from different scales and from an integrated multi-criteria and multi-scale approach. The tool is available in four languages: French, Deutsch, German and English. It is completely responsive to all devices and can be used on any browser.

The urban fabric is defined in different layers of datasets. Six scales have been integrated: the region, the municipalities, the neighbourhoods, the statistical sectors, the city blocks and the buildings. Only dwellings built before 1945 were considered. All the layers are linked through a top-down approach so different scenarios of retrofitting can be proposed and assessed at any scale by a transversal heritage, environmental and energy evaluation. The key is probably to consider these aspects in a non-compartmentalized and complementary way, in order to reach a global objective through a sustainable and responsible approach.

The methodology used to generate the database is described in previous papers (Trachte et al.). It provides reliable outcomes based on several hypotheses. Thirteen indicators were defined to help the user proposing suitable urban or architectural interventions in each situation preserving heritage value and with relevant energy performances, materials and systems.

This paper presents five scenarios of evolution of the dwelling stock defined and analysed using B³-RetroTool. So far, the tool includes available information of the buildings built before 1945. Nevertheless, the structure of the tool allows an easy update, to include more accurate data on the initial state of the building stock or to consider other types of buildings. In addition, if, at this point, the tool can only be used to analyse Brussels Capital Region, the methodology can be applied to other regions in the world. Enlarging the scope of this tool can help to meet the environmental, social and economic challenges of the contemporary world and to foster the transition of building sector towards a sustainable development.

BUILDING TYPES

Seven dwelling types (and sub-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 (Trachte et al., 2014):

- Type 1: “Maison bourgeoise” buit before 1875
- Type 2: Typical “Maison bourgeoise”
- Type 3: “Maison de rapport” / “Hôtel particulier”
- Type 4: Modest or worker houses
- Type 5: Evolution of “Maison bourgeoise”
- Type 6: Apartment building
- Type 7: Dwellings built after 1945

ANALYSING EXISTING BUILDING STOCK

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 (Trachte et al., 2014).

A software called Energy Metric (Stephan, 2013), giving an approximate value for energy consumption (heating, energy use for domestic hot water and electric appliances consumption) and a bill of all material used, was then used to model all types of buildings in their "initial state" (as they were built, i.e. with no insulation) and when applying various proposals for their retrofitting. More than 2500 cases were thus simulated (Trachte et al., 2015). As this research was focused on dwellings built before 1945, no retrofitting is proposed in the tool for those buildings, grouped in type 7. This type is only considered to have a representative overview of existing building stock in Brussels Capital Region. A specific building characterization was chosen for these buildings depending on the date of construction (linked with corresponding energy performance of current regulation) and the number of dwellings per lot. It is important to notice that buildings of type 7 are responsible for approximately 52% of the energy consumption of the region (8900 GWh).

Unfortunately, it was not possible to find precise information on the actual state of each building built before 1945. Based on many discussions with Brussels stakeholders and a trend analysis performed on the renovation of housing awarded as "Exemplary Buildings" (BATEX) in Brussels, it was decided to consider, for all scenarios, that some buildings would already be retrofitted, at least partially, in 2020. An upgraded envelope, illustrated in Fig. 1, is considered for a certain share of each building type: 30% of types 1 and 3, 50% of types 2, 4a, 5 and 6, and 20% of type 4b. Improved roof and walls have a thermal conductivity of $U_{wall} = U_{roof} = 0.24$ W/m^{2}K and improved windows have a thermal conductivity of $U_{window} = 1.5$ W/m^{2}K, using fossil based insulation and wood framed windows. Improved systems for ventilation (type C: mechanical extraction, medium air tightness), heating and domestic hot water production (efficiency of 80%) are also chosen for these upgraded buildings. All other buildings are considered to be in their initial state. No solar panel or systems for rainwater recovery is considered at this point.

SCENARIO 1: BAU

The first scenario of evolution, proposed as the default scenario in B^3-RetroTool, is called "BAU" (Building As Usual). It is defined to correspond to the evolution that will happen if the rate of significant retrofitting stays identical until 2050 (today it is estimated to be around 1%/year) and if the energy performance of the buildings

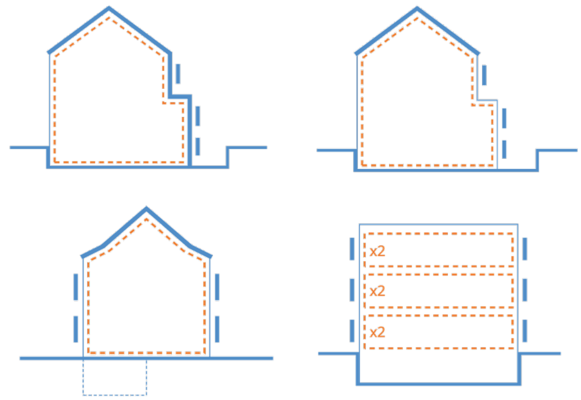

Figure 1: Improved envelopes in 2020 (top-left: types 1 and 3; top-right: types 2, 5; bottom-left: type 4: bottom-right type 6).

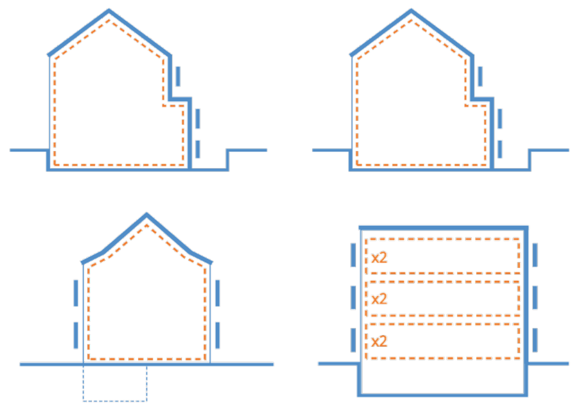

Figure 2: Scenario 1 – Improved envelopes (top-left: types 1 and 3; top-right: types 2, 5; bottom-left: type 4: bottom-right type 6).

after retrofitting is rather limited (today most of existing building are not submitted to EPB regulation). Only buildings in their initial state are improved.

Improved envelopes, illustrated in Fig. 2, are applied to respectively 10% of analysed building stock in 2030, 18% in 2040 and 26% in 2050. Again, improved roof and walls have a thermal conductivity of $U_{wall} = U_{roof} = 0.24$ W/m^{2}K and improved windows have a thermal conductivity of $U_{window} = 1.5$ W/m^{2}K, using fossil-based insulation and wood framed windows. For all retrofitted buildings, improved systems for ventilation (type C: mechanical extraction, medium air tightness), heating and domestic hot water production (efficiency of 80%) are chosen. No solar collectors or photovoltaic panels, and no specific systems for rainwater recovery, are installed.

SCENARIO 2: LOW-ENERGY

The second scenario of evolution is called "Low Energy" because it considers that all retrofitted buildings until 2050 will reach high-energy standards. It is defined with the same rate of retrofitting as scenario 1 (1%/year). Only buildings in their initial state are improved.

Upgraded envelopes, illustrated in Fig.3, are applied to respectively 10% of analysed building stock in 2030, 18% in 2040 and 26% in 2050. Here, improved roofs and walls have a thermal conductivity of $U_{wall} = U_{roof} = 0.15$ W/m^{2}K and improved windows have a thermal conductivity of $U_{window} = 0.8$ W/m^{2}K, using fossil-based insulation and wood framed windows. For all retrofitted buildings, improved systems for ventilation (type D: double flow, heat recovery 90%, high air tightness), heating and domestic hot water production (efficiency of 90%) are chosen. No solar collectors or photovoltaic panels, and no specific systems for rainwater recovery, are installed.

SCENARIO 3: RENO2%

The third scenario of evolution is called "Reno2%" because it considers that the rate of significant retrofitting is doubled compared to scenario 1 (2%/year). Again, only buildings in their initial state are improved.

The energy performance of the buildings after retrofitting, as well as the type of systems installed, are considered to be the same as in scenario 1. Upgraded envelopes are applied to respectively 18% of analysed building stock in 2030, 33% in 2040 and 45% in 2050.

No solar collectors or photovoltaic panels, and no specific systems for rainwater recovery, are installed.

SCENARIO 4: RENO_T2-5

The fourth scenario of evolution is called "Reno_T2-5". It is based on the observation that building types 2 and 5 represent a large share of the dwellings built before 1945 (almost 60%).

In this scenario, the rate of significant retrofitting is doubled (2%/year) for types 2 and 5, and stays identical to scenario 1 (1%/year) for the other types. For types 2 and 5 respectively 18% of analysed building stock is retrofitted in 2030, 33% in 2040 and 45% in 2050. As previously, only buildings in their initial state are improved. The occupation of those buildings is increased: two dwellings per building for types 2a and 5a (small houses), three dwellings per building for types 2b, 2c, 5b and 5c (medium and large houses), and five dwellings per building for type 5d (very large houses).

Building envelope and systems are upgraded as in scenario BAU for all types, except that for types 2 and 5, cellulose insulation is used for the walls and the roof, and that some complementary systems are added: 15 m^2 of photovoltaic panels and 5 m^2 of solar collectors, as well as a system to recover, store and use (toilet) 60% of rainwater falling on the roof.

SCENARIO 5: ENV

The fifth scenario of evolution is called "ENV", for "Environment". It considers a relatively high level of performance of the envelope and the systems, but using recycled insulation and implementing complementary systems to recover solar energy and rainwater. In addition, front façade are almost not retrofitted to preserve heritage value of existing buildings and occupation level is increased to face increasing demand.

Improved envelopes, illustrated in Fig. 4, are applied to respectively 10% of analysed building stock in 2030, 18% in 2040 and 26% in 2050. As in scenario BAU, improved roof and walls have a thermal conductivity of $U_{wall} = U_{roof} = 0.15$ W/m^{2}K and improved windows have a thermal conductivity of $U_{window} = 0.8$ W/m^{2}K, but this time using cellulose insulation and wood framed windows.

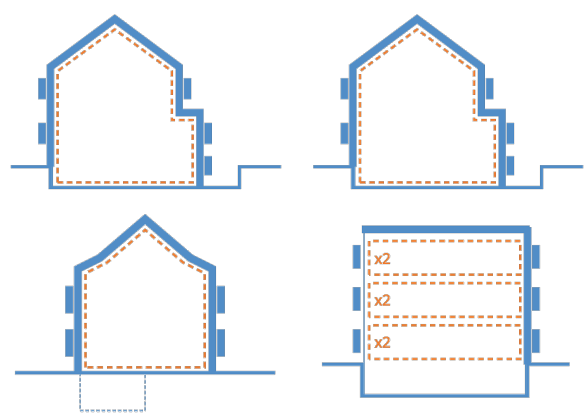

Figure 3: Scenario 2 – Improved envelopes (top-left: types 1 and 3; top-right: types 2, 5; bottom-left: type 4: bottom-right type 6).

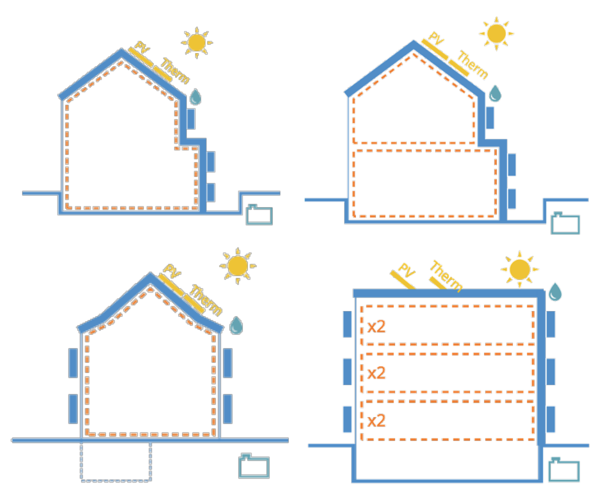

Figure 4: Scenario 5 – Improved envelopes (top-left: types 1 and 3; top-right: types 2, 5; bottom-left: type 4: bottom-right type 6).

For all retrofitted buildings, improved systems for ventilation (type D: double flow, heat recovery 90%, high air tightness), heating and domestic hot water production (efficiency of 90%) are chosen. 15 m^2 of photovoltaic panels and 5 m^2 of solar collectors, as well as a system to recover, store and use (toilet) 60% of rainwater falling on the roof (saving 25% of water consumption), are installed in all retrofitted buildings. The number of dwellings per building is increased for types 2 and 5: two dwellings per building for all sub-types except 5d (very large houses), assigned with three dwellings per building.

ENERGY INDICATORS

The first indicator that can be used to compare these scenarios is the annual energy consumption. It integrates the heating consumption, domestic hot water production and electric devices consumption of each building. Fig. 5 shows the evolution of total annual energy consumption of all dwellings in BCR for the five scenarios. It appears that global energy savings are the highest for scenario 2, but followed closely by scenario 3 and 5. It has to be noticed that a part of the energy supply comes from solar collectors and PV panels in scenario 4 (136 GWh/year in 2050) and scenario 5 (119 GWh/year in 2050).

Beside total annual energy consumption, B^3-RetroTool also allows analysing embodied energy of materials needed to retrofit the buildings, as illustrated in Fig. 6. Here, scenario 4 and 5 implies the least embodied energy in the long term. The values are based on the bill of material obtained by the software Energy Metric combined to the data from Ecosoft database. Embodied energy from HVAC system and solar panels are not considered.

ENVIRONMENTAL INDICATORS

B^3-RetroTool allows analysing many environmental indicators: Bill of materials (par category, in kg or m^3); CO_2 emissions due to energy consumption (it is assumed that heating and domestic hot water use public network gas) and to materials production (only CO_2 is accounted, not the other GHG); Water consumption and possible infiltration of rainwater.

It is interesting to notice that most of material needed to retrofit existing buildings is the insulation material (XPS and cellulose in these cases), as presented in Fig.7.

The trends of the evolution of CO_2 emissions is very similar the corresponding energy indicators (annual energy consumption and embodied energy of materials). In 2050, the tool calculates a CO_2 emission due to annual energy consumption of 288000 tons for scenario 1 (scenario with the highest value) and 270000 tons for scenario 2 (scenario with the lowest value). CO_2 emission due to the production of materials used in the retrofit is 9200000 tons of CO_2 for scenario 2 (scenario with the highest value) and 8769000 tons in scenario 5 (scenario with the lowest value).

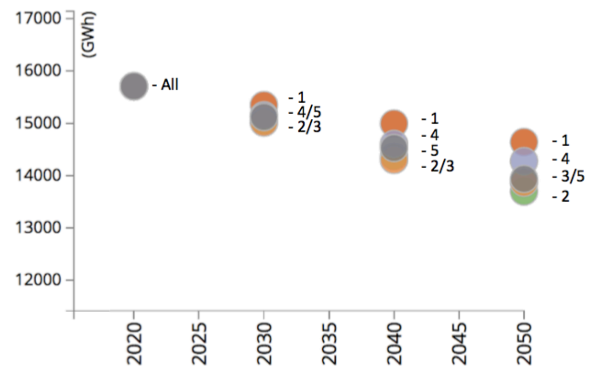

Figure 5: Evolution of annual total energy consumption of dwellings in BCR for the five scenarios.

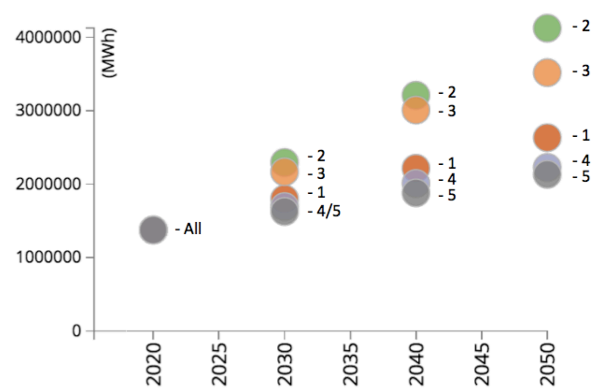

Figure 6: Evolution of total embodied energy of materials used to retrofit the dwellings in BCR for the five scenarios.

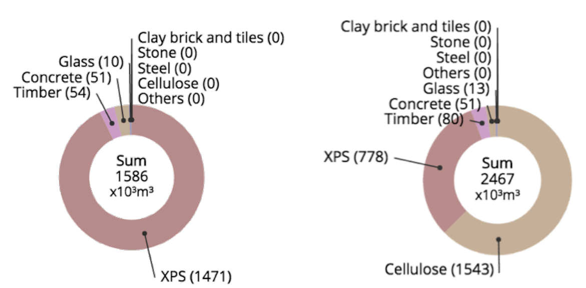

Figure 7: Bill of materials (in m^3) used to retrofit the buildings for scenario 1 (left) and scenario 5 (right).

HERITAGE VALUE INDICATORS

Heritage value of BCR is considered to be mainly due to existing building built before 1945. Therefore three specific indicators, assessing the risk of loosing a part of the heritage value, were defined, accounting the impact of modifications on either the envelope or the HVAC systems, or the impact of installing solar energy production (Trachte, 2015). The following indicators are also proposed to the user: Number of dwellings, Number of lots, Surface of lots, Built area, and Heated area.

Fig. 8 shows the evolution of the total number of dwelling in BCR. It appears that it is possible to have almost 70000 more dwellings by the year 2050 if building types 2 and 5 are reorganised, as in scenario 4 (24000 more dwellings in 2050 with scenario 5).

Fig. 9 shows that appropriate design efforts must be made to avoid loosing heritage value. The risk is much higher in scenario 2 than in any other scenario, as there is around 25% of existing buildings with a significant risk and almost 50% with a moderate risk.

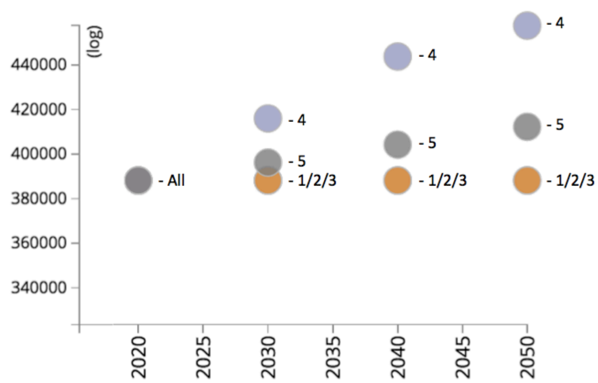

Figure 8: Evolution of the total number of dwelling in BCR for all scenarios.

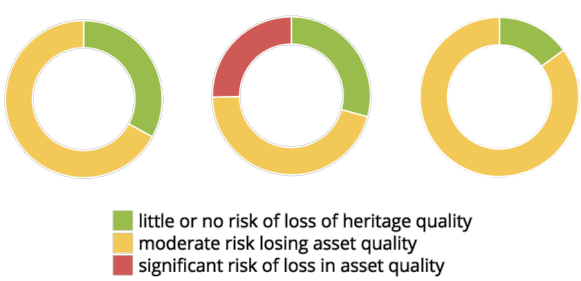

Figure 9: Risk of decreasing heritage value because of the modification of the envelopes in 2050 for scenario 1 and 5 (left), scenario 2 (middle) and scenario 3 (right).

DISCUSSION

The amount of information available in B3-RetroTool is very large. The tool can be used to analyse the evolution of existing buildings at different scale. This paper presents the analysis of five general scenarios of evolution at the largest scale, the scale of the region.

It has to be noticed that the tool is focused on the retrofitting of dwellings built after 1945. It does not consider any new buildings or any transformations of buildings that were not initially designed as dwellings. In addition, it is based on a rather incomplete database of existing building in Brussels Capital Region. Many assumptions were made to model the entire city. An important research effort should be made in the next decade to gather necessary data on Brussels (and other regions) to benefit fully of the potential of the methodology used in B3-RetroTool. As announced, the improvements made to existing buildings were applied, in all scenarios, only to the buildings that were never improved before. Being in their initial state, the effects of the retrofitting are significantly higher. As a matter of fact, on the energy point of view for example, without choosing to do so, energy saving would have been twice smaller. This should influence the definition of future regulations.

The first result to discuss concerns the energy used by the dwellings at the scale of the region. As shown on Fig. 5, improving existing building at a high level of energy performance (scenario 2), but at the same rate at we do it today, increase significantly the energy savings compared to scenario 1. If the rate of retrofitting were doubled (scenario 3), the effect is similar at least 20 or 30 years (after, as there are less and less buildings that were never renovated, this may not be true anymore and some of the retrofitted buildings should also be improved to increase global energy savings).

As illustrated in Fig. 8, the number of dwellings increases in scenarios 4 and 5. When the average of energy consumption per dwelling, presented in Fig. 10, is analysed, those two scenarios appear to be the most efficient. Increasing the number of dwelling in Brussels is an urgent matter considering its social evolution. It is a important opportunity to increase the average energy efficiency per dwellings.

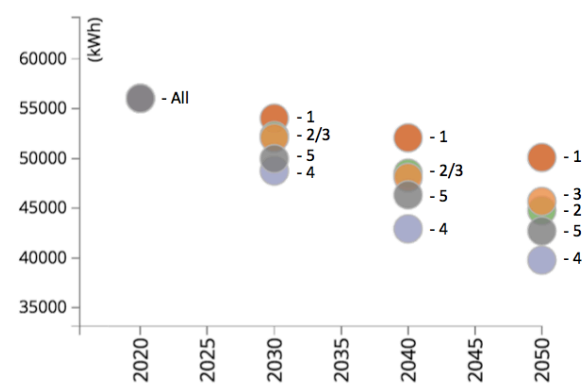

Figure 10: Evolution of average energy consumption per dwellings in BCR for the five scenarios.

The second important results to discuss are the embodied energy of materials used in the retrofitting of the buildings. As presented in Fig. 6, energy improvements of existing building implies to spend energy to produce building materials. In scenario 2, the most efficient in terms of energy, embodied energy spent in 30 years is around 4000 GWh. The retrofit proposed in this scenario allows energy savings of 2000 GWh/year (compared to estimated state in 2020). This amount of energy to produce material should thus not be neglected and it can be greatly reduced when choosing appropriate materials, as proposed for example in scenario 5. Unfortunately, B^3-RetroTool does not consider embodied energy of complementary systems (HVAC, solar panels, water management systems…) and more information on this topic should be gathered in the next decade to consider their effect on global sustainability.

The third topic discussed in this paper is the importance to analyse the effect of retrofitting strategies on a multi-criteria basis. Increasing energy efficiency can be made with a limited impact on environment and heritage value on the long term, but some reasonable choices have to be made in terms of materials, systems (HVAC, renewable energy production, water management systems) and occupation. For example, increasing the number of dwellings, as in scenario 4 and 5, can have a limited impact on global water consumption if it is combined with a system to reuse rainwater. Scenario 3 and 5 obtain almost the same results in terms of energy than scenario 2, but they are much more interesting in terms of the risks to decrease global heritage value.

A last topic that could have been discussed is the financial costs of each scenario. Assessing the average costs of retrofitting is possible, but it has a high level of uncertainty. This topic is out of the scope of B^3-RetroTool, but should be addressed seriously in the next decade.

CONCLUSION

B^3-RetroTool is a powerful tool to analyse existing dwellings stock of Brussels Capital region (BCR) and to define appropriate strategies through an integrated multi-criteria and multi-scale approach. This paper is only an example of the results it can lead to.

Five scenarios were presented and the results were compared and discussed. It appears that aiming a high efficiency of buildings must be associated with a careful attention on the choice made in terms of materials, systems and occupation. If global energy consumption may often be seen as the main issue, it appears that we will have to consider many other indicators in the future.

The paper showed that increasing the rate of renovation is an excellent way to support important energy savings. It also showed that embodied energy needed to produce the building materials used in the retrofitting can be limited, as the corresponding CO_2 emissions, with similar results in terms of global energy consumption. In addition, increasing the number of dwellings available in the city can have a limited impact on energy and water consumptions if solar panels are installed and if rainwater is reused.

As the identity of Brussels is largely due to its buildings, the tool used in this research identifies a risk of decreasing heritage value when the initial typology of the building may be definitively altered after retrofitting. Of course, many creative architects and designers showed that it is possible to combine high energy efficiency and heritage preservation, but this difficult task must receive a specific attention. The paper presents some scenarios of evolution with minimal risks on heritage value.

This work may influence building sector stakeholders in Brussels and should promote the necessary transition of this sector. The first step may be to work on a shared and sufficiently representative database to model the dwellings stock.

At this point, the tool can only be used to analyse Brussels Capital Region, but the methodology can be applied to other regions in the world. Enlarging the scope of this tool can help to meet the environmental, social and economic challenges of the contemporary world and to foster the transition of building sector towards a sustainable development.

ACKNOWLEDGEMENTS

This research was conducted at Architecture et Climat, Université catholique de Louvain, based on the web tool developed in partnership with BATir, Université Libre de Bruxelles. It was funded by INNOViris as part of the strategic environment platform “Brussels Retrofit XL” coordinated by Belgian Building Research Institute.

REFERENCES

Trachte, S., Evrard, A., Galan A., Athanassiadis, A. (2014). Assessing Sustainable Retrofit of the old Dwellings Stock in Brussels Capital Region. Proceedings of PLEA2014, CEPT University, Ahmedabad.

Stephan, A. and Crawford, R.H. (2013). A multi-scale life-cycle energy and greenhouse-gas emissions analysis model for residential buildings. *Architectural Science Review*: 1-10, Taylor & Francis.

Trachte, S., Galan A., Evrard, A., Athanassiadis, A. (2015). B^3-RetroTool: Development of a multi-scale and multi-criteria pre-assessment tool for the sustainable retrofit of Brussels Capital Region. Proceedings of 2ème congrès interdisciplinaire du développement durable, Louvain-la-Neuve.