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TCS Matrix: Evaluation of optimal energy retrofitting strategies.

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Abstract

Renovating the existing building stock is well recognized in the construction industry as a very important issue. While the number of new buildings annually provides maximum 1% to the building stock, the other 99% represent buildings which are already built. Studies show that the environmental impact to extend the life of a building is definitely smaller than that of demolition and new construction. Recent figures suggest that the residential sector can provide significant reductions in energy consumption.
As many vital decisions are taken in the early stages of the refurbishment process, planners need tools that will help them create better and more sustainable retrofitting projects based on the improvement of the building energy performance.
This study describes a methodology to support decision making in the retrofitting of the existing building stock of the Leopold Quarter in Brussels to enable the development of an integrated strategy for different cases and specifications. It is intended that the planners know since an early stage, the energy impact of the project according to the selected interventions.
All the proposed retrofitting strategies are compiled in a database that is the basis of the tool named TCS Matrix (TCS stands for: Typology, Component, Solution).
This paper provides an insight of the methodology to create the aforementioned databases as well as a series of scenarios that supposes a first step of the aimed methodology to identify in an early stage the best solutions for this specific part of the building stock to achieve the energy efficiency targets defined by the Energy Performance of Buildings Directive.

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1. Introduction

Renovating the existing building stock is well recognized in the construction industry as a very important issue. While the number of new buildings annually provides maximum 1% to the building stock [1], the other 99% [2] represent buildings which are already built. Studies show that the environmental impact to extend the life of a building is definitely smaller than that of demolition and new construction [3]. Recent figures suggest that the residential sector can provide significant reductions in energy consumption [4].

According to the Directive 2010/31/EU [5], new buildings will have to be nearly zero energy buildings by 31st December 2020. However, the directive does not give any specific targets regarding refurbished buildings, which present a large proportion of the building stock and is the first cause of Carbon Dioxide (CO_2) emissions in the building sector.

Gaterell and McEvoy suggest that the domestic sector could potentially make a significant contribution to reducing energy consumption. Residential buildings account for the 2/3 of final energy consumption in the building sector and 70% of buildings' floor area, so it seems important to focus on the improvement of energy efficiency in the existing residential building stock. [6]

Studies have concluded that a deep retrofitting is the ideal solution from an ecological and economic perspective, and that surface renewals only contribute to increasing the risk of losing the set climate targets and not exploit the potential total savings [7]. The urban fabric of European cities is largely shaped by old and inefficient residential buildings whose energy demand can exceed 200kWh / m² per year [8].

However, although the need for integrated solutions to maintenance and retrofitting is well known by the construction sector actors, no need for specific knowledge on how and when to apply successfully the maintenance, management, adaptation, transformation and redesign is defined [9]. Moreover, many vital decisions are taken in the early stages of the design process that can determine the success or failure of the design, as a decision made earlier can have a bigger impact with less effort. Architects need tools that help them to create better and more sustainable retrofitting projects [10].

It is necessary, though, to develop a methodology to tackle the energy retrofitting of residential buildings that assures success since the design phase. There is an individual and often fragmental approach to the energy retrofitting projects even when the solutions are applied in an individual residential building.

This paper discusses an approach to the design of refurbishment projects, as a way to improve the energy efficiency of the residential stock. It presents answers to specific technical problems and proposes a series of scenarios to enhance the energy performance. The discussion starts introducing the so called, TCS Matrix tool (Typology-Component-Solution), which is the centerpiece of the approach, to later present how the TCS matrix is used through to support the methodology.

2. Energy efficiency retrofitting methodology

Dwelling retrofitting is taking a central place in the efforts for integral refurbishment and revitalization of larger areas, especially in larger housing states [11]. The concept of sustainable refurbishment should cover and integrate economic, social and environmental needs as much as possible.

There exists numerous studies dealing with the question from different perspectives: Reddy, Srinivas and Jagannathan [12] offer a frame-based decision support model for building refurbishment, while Rosenfeld and Shohet [13] and Lavy and Shohet [14] talk about a decision support model for semi-automated selection of retrofitting alternatives. Alanne [15] proposes a multi-criteria model to help designers choose the most feasible refurbishment actions in the conceptual phase of the project.

One of the most interesting approaches with the aim to deliver a useful methodology is that proposed in the study of Konstantinou and U. Knaack [16]. A toolbox in the form of a matrix is proposed to accelerate the construction process. This defined toolbox identified the building in components and solutions. It can be considered as a huge step in the process of standardizing the construction process and is a knowledge basis for the TCS Matrix.

Nevertheless there are three elements that are missing from their toolbox, and that could be considered critical to ensure the success and reusability of the model. Firstly, this model is focused on a typology of building, and is to be redefined in each work. This constraint triggers the need to extend the toolbox with the inclusion of building typologies, as components and solutions are roughly the same in a building typology. Secondly, and based on the Deming cycle (Figure 1), the toolbox lacks of a continuous improvement process that would allow the system to learn from its deviations. Deming cycle is also defined as the PDCA (Plan-Do-Check-Act) model: an iterative four-step management method used in business for the control and continuous improvement of processes and products. By the introduction of these Knowledge Management concepts, the update and retrofit of the information is assured. Finally, Konstantinou and Knaack toolbox does not offer the possibility of being parameterized to calculate the efficiency based on different constraints such as the cost of the implementations.

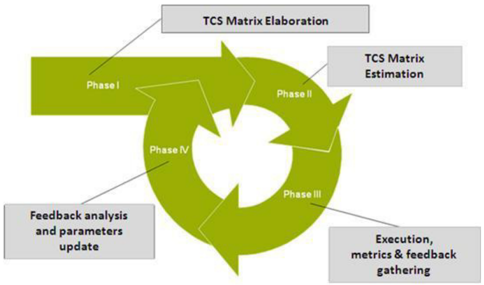


Fig. 1. Deming Cycle TCS Matrix

2.1. Decision making process

Depending on the rehabilitation objectives required in each case, various solutions could be found. The aim is not to give an optimal solution but to help [4] make right choices without compromising the interests of the designer, client or user. To this end, the so called matrix TCS (TCS stands for Typology, Component, Solution) is defined. This matrix aims to gather all the measures that could be applied in the retrofitting of the defined stock, sorted by building typology and main building components. The target is to offer different retrofitting solutions and their overall impact in the decrease of energy demand. The measures provided are all extracted from previous retrofitting interventions from literature review. The TCS matrix aims, though, to improve the design process by providing retrofitting strategies for different building typologies and specific configurations, without limiting the designer choice.

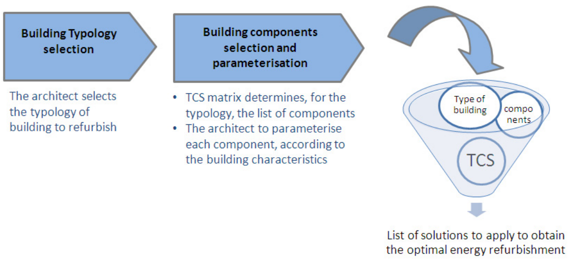


Fig. 2. Concept of Optimal retrofitting

In future steps, the retrofitting strategies and their energy efficiency value are expected to be complemented with an economic evaluation to help the designers to provide the cost-optimal retrofitting to clients while obtaining the expected new energy performance.

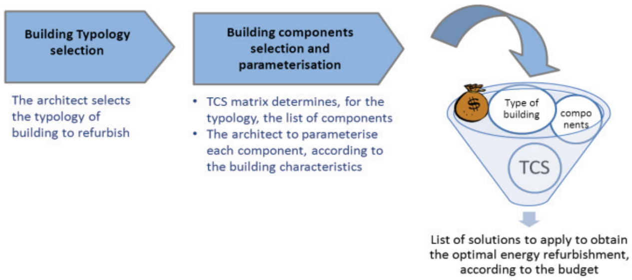


Fig. 3. Concept of Cost-Optimal Retrofitting

3. Old residential buildings: Stating the problem

Building retrofitting can be considered as one of the most culturally enriching architectural strategies, as the expression of different historic periods makes the built environment much richer. Reusing existing buildings can be, thus, an efficient way of spreading culture, to which respect to previous interventions is necessary (APUR, September 2013 #80).

The buildings selected for this study are those located in the Leopold Quarter in Brussels. This Quarter, suffered a very quick and homogeneous growth back in the late XIX century. The homogeneity of this built environment makes easy to gather the exiting building stock by typologies as the aim of this study is to provide retrofitting measures for all the building stock. Another strong reason is his privilege and, however, risky location in the heart of the European quarter. The need of tertiary buildings to accommodate the offices of the European Commission leads to the demolition of an important part of the neighbourhood during the second half of the XX century, emphasising the idea that old buildings could not fulfil the new living and working needs.

These old buildings are generally un-insulated heavyweight constructions, so the common approach to the retrofitting is based on the improvement of the envelope. However, modern construction techniques have to be carefully applied to old buildings, which have a delicate thermal balance. Yet old buildings have severe drawbacks that prevent them from good environmental performance: poor daylight, high-energy consumption or limited opportunities for natural ventilation are common characteristics of this housing type [1] what might seem an improbable target for development of energy efficiency dwellings. However, the scope for improvement is certainly large and the benefits of their preservation go beyond mere technical considerations. On the one hand, they are valuable constructions that must be especially protected. On the other hand, they are buildings whose inadaptability to current demand can be a threat to their preservation.

Nowadays, to reduce the energy demand in buildings is translated, in the existing building stock, in the implementation of renovation solutions stipulated in the different regulatory frameworks. The Directive of the European Parliament and Council on the Energy Performance of Buildings [5] imposes to the member states to adopt tools to calculate the energy performance, to apply minimum regulation on energy performance in the renovation works, to certificate the buildings and to assure the control of the heating and cooling systems.

The implementation of these interventions in the ancient building stock is facing numerous problems that need to be evaluated to obtain the expected reduction in the energy demand. In fact, the impact of these measures has not yet been assessed at a large scale, as no data from previous interventions is available.

3.1. Building typologies catalogue

The TCS matrix tool is developed and applied in the context of the upcoming refurbishment of residential buildings in the Leopold quarter. The revitalization of old cities would imply the increment of dwelling availability in areas where greater social diversity is needed and higher population density can be beneficial. The older the construction, the more delicate and necessary the upgrading process is and the more specialized the knowledge is required.

This paper focuses on the study of the context and the identification of the main characteristics that are common to the old dwelling stock of Leopold Quarter in Brussels, linked to their energy performance.

The first task to be accomplished is to define the building catalogue. The methodology proposed is based in the description of the components that characterize each typology. The first problem encountered was that there was not an official definition and quantification of the building types of the area, so it has to be created. What was a problem in the beginning, resulted to be an interesting approach to classify and map historic building stocks.

With the help of Python® software, a list of the building typologies was defined as well as its percentage over the overall of the typology in Brussels (Table 1).

Table 1. Number of buildings by typology. Leopold Quarter.

Type	Number of Buildings	Building typology – Leopold Quarter	Percentage of number of buildings over Brussels Capital Region (BCR)
1	8	*Neo-classic Maison Bourgeoise*	0.29%
2a	774	*Maison Bourgeoise with bel étage (1 dwelling)*	3.89%
2b	1032	*Maison Bourgeoise with bel étage (>1 dwelling)*	4.97%
3a	254	*Hôtel de Maître or Hôtel particulier*	5.81%
3b	55	*Maison de rapport*	4.73%
4a	48	*Modest House before 1919*	0.56%
5	47	*Apartment building*	3.31%
TOTAL	**2218**		

With the help of ArcGis® mapping tool, is the first time that the typologies integrating the neighbourhood have been mapped, being considered the first interesting outcome of this study. (Figure 4)

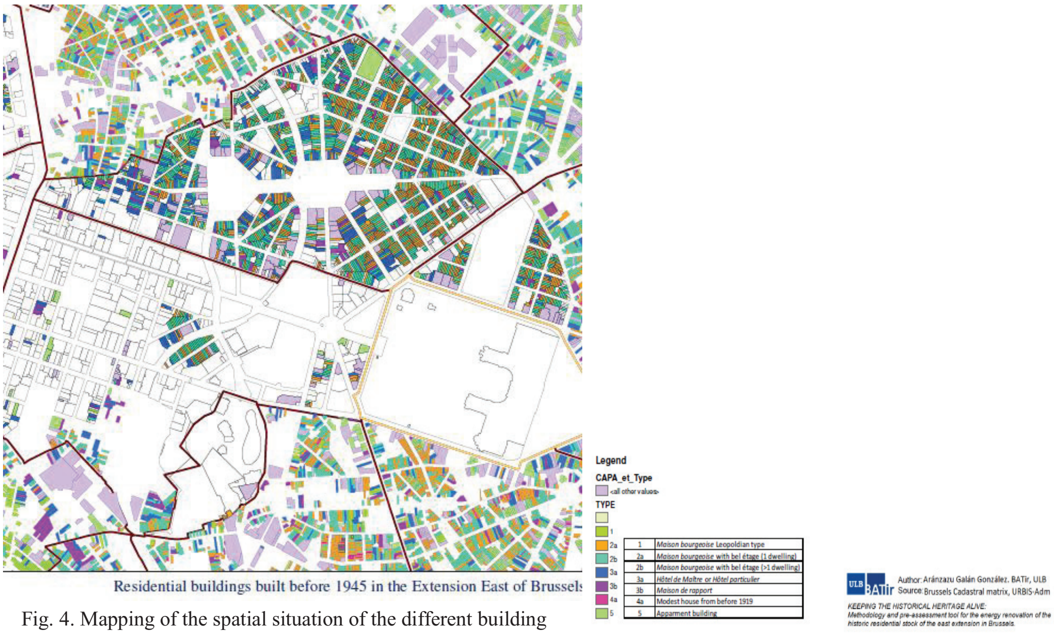


Fig. 4. Mapping of the spatial situation of the different building typologies inside the selected area

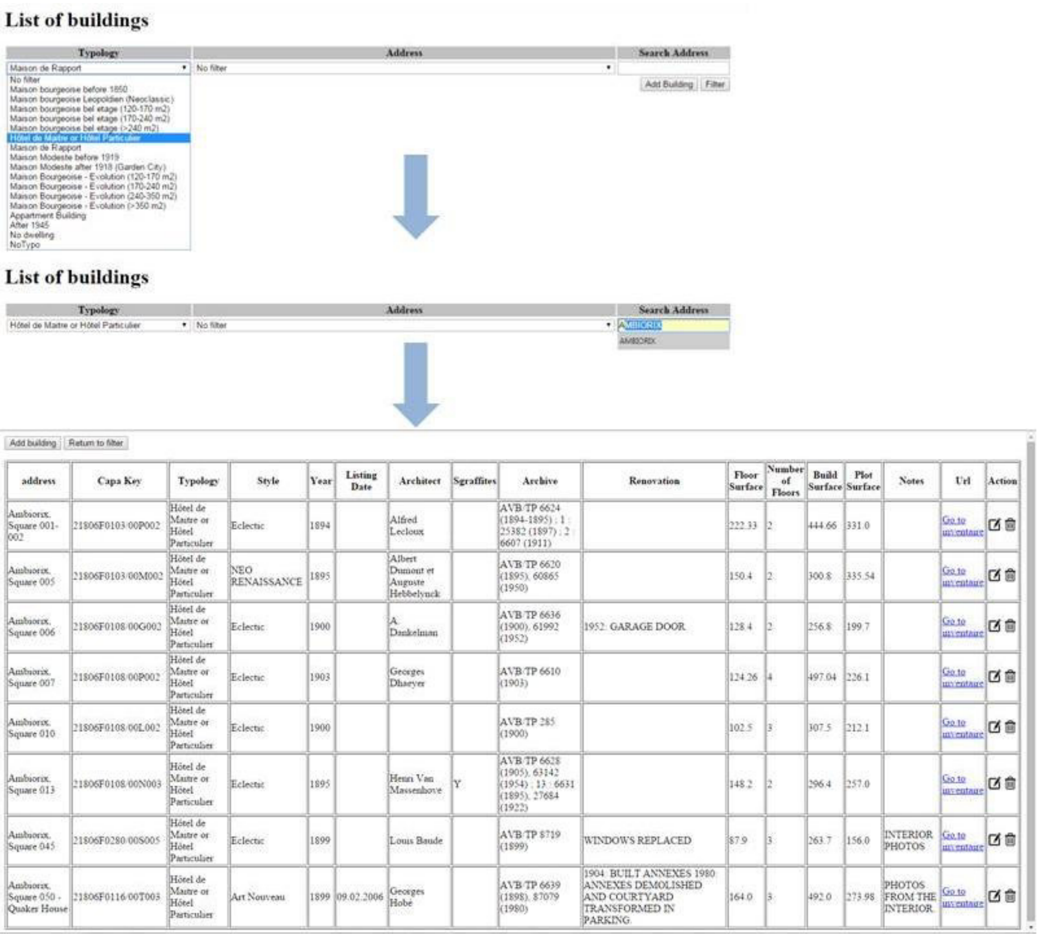
The dwellings fall under two big periods:

- From 1830 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 1930: emergence of apartment building (building modest, standard and / or high status) that takes his real development after 1930.

This paper tries to emphasise that by a deep analysis of the building typologies, the designer could have a better understanding of the particularities of the stock. After the building stock definition, a more practical approach is required. Figure 5 shows the tool developed in this research to classify all the dwellings embodied in the studied building stock. Even when the retrofitting measures will be developed for the whole stock, all the buildings of the area are classified using GIS tools. This will enable the implementation of the final database in the future.

The filters system, allows an easy comparison of the dwellings facilitating the selection of those that will be consider as case of study.

Maps of every individual topic could be provided, depending of the interest of the user, as well as individual databases.



address	Capa Key	Typology	Style	Year	Listing Date	Architect	Sgraffites	Archive	Renovation	Floor Surface	Number of Floors	Build Surface	Plot Surface	Notes	Url	Action
Ambiorix, Square 001-002	21806F0103/00P002	Hôtel de Maitre or Hôtel Particulier	Eclectic	1894		Alfred Lecloux		AVB/TP 6624 (1894-1895) ; 1 ; 25382 (1897) ; 2 ; 6607 (1911)		222.33	2	444.66	331.0		Go to inventaire	
Ambiorix, Square 005	21806F0103/00M002	Hôtel de Maitre or Hôtel Particulier	NEO RENAISSANCE	1895		Albert Dumont et Auguste Hebbelynck		AVB/TP 6620 (1895), 60865 (1950)		150.4	2	300.8	335.54		Go to inventaire	
Ambiorix, Square 006	21806F0108/00G002	Hôtel de Maitre or Hôtel Particulier	Eclectic	1900		A. Dankelman		AVB/TP 6636 (1900), 61992 (1952)	1952: GARAGE DOOR	128.4	2	256.8	199.7		Go to inventaire	
Ambiorix, Square 007	21806F0108/00P002	Hôtel de Maitre or Hôtel Particulier	Eclectic	1903		Georges Dhaeyer		AVB/TP 6610 (1903)		124.26	4	497.04	226.1		Go to inventaire	
Ambiorix, Square 010	21806F0108/00L002	Hôtel de Maitre or Hôtel Particulier	Eclectic	1900				AVB/TP 285 (1900)		102.5	3	307.5	212.1		Go to inventaire	
Ambiorix, Square 013	21806F0108/00N003	Hôtel de Maitre or Hôtel Particulier	Eclectic	1895		Henri Van Massenhove	Y	AVB/TP 6628 (1905), 63142 (1954) ; 13 ; 6631 (1895), 27684 (1922)		148.2	2	296.4	257.0		Go to inventaire	
Ambiorix, Square 045	21806F0280/00S005	Hôtel de Maitre or Hôtel Particulier	Eclectic	1899		Louis Baude		AVB/TP 8719 (1899)	WINDOWS REPLACED	87.9	3	263.7	156.0	INTERIOR PHOTOS	Go to inventaire	
Ambiorix, Square 050 - Quaker House	21806F0116/00T003	Hôtel de Maitre or Hôtel Particulier	Art Nouveau	1899	09.02.2006	Georges Hobe		AVB/TP 6639 (1898), 87079 (1980)	1904: BUILT ANNEXES 1980: ANNEXES DEMOLISHED AND COURTYARD TRANSFORMED IN PARKING	164.0	3	492.0	273.98	PHOTOS FROM THE INTERIOR	Go to inventaire	

Fig. 5. Building catalogue tool

3.2. Scenarios of Sustainable retrofitting

All the seven typologies integrated in the neighbourhood are studied and simplified in schemas that highlight, in a first step, the typology characteristics. The *Maison Bourgoise* is selected to illustrate the methodology. This typology is characterised by a plan with two or three rooms in a row and 4 or 5 floor levels.

An example of this representation system is given below (Figure 6). All this methodology is focused to built the layout of the tool that will offer a friendly front-end to the user that could quickly identify the typology he is working in. The special features of each building will be identified, so the dwelling is fully defined.

(*Bel étage* is translated in English as “noble floor” but it does not correspond to the construction system of this housing typology, so the French definition has been adopted)

Fig. 6. Mapping of the spatial situation of the different building typologies inside the selected area

In a second step, Critical information is gathered:

- Real-life legal situation (implying ability/inability to initiate refurbishment): there can be different strategies depending on whether you can refurbish a whole or part of a whole house.
- Legal status: Different strategies would be taken into account depending in the protection of some of the parts of the building.
- Built construction typologies :
  - Materials (thickness, U values, humidity issues, air tightness, etc.)
  - Bulk and compactness (heated net volume, heat loss surface, compactness)
  - Orientation, m² of windows, etc.
- Building systems :
  - Heating generation
  - Hot water storage
  - Heat distribution
  - Ventilation system
  - Existence of electric generation system
  - Lightning, etc.
- For each criteria, min/max and average values will be defined and the scenarios to maximize them.

Based on the description of each dwelling type and its main characteristic, various scenarios of retrofitting were proposed. They focused mainly on improving the energy performance of each dwelling type. Each of the scenarios is analyzed one by one including a data sheet where it would appear the energy consumption before the intervention, the cost of the intervention and the new energy consumption after the intervention.

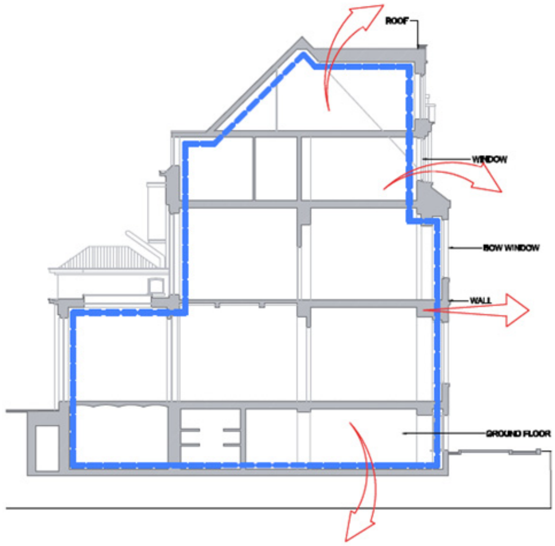


Fig. 7. Representation schema of the thermal envelope and heat transfer.

1. Scenarios for envelope retrofitting (Figure 8)

The envelope retrofitting scenarios are defined based on a trend analysis performed on the retrofitting of housing awarded at *Exemplary Buildings* initiated by Brussels Environment.

The retrofitting steps are proposed by hierarchy, taking into account the state of the dwelling, the influence on the energy performance and the extent of work required.

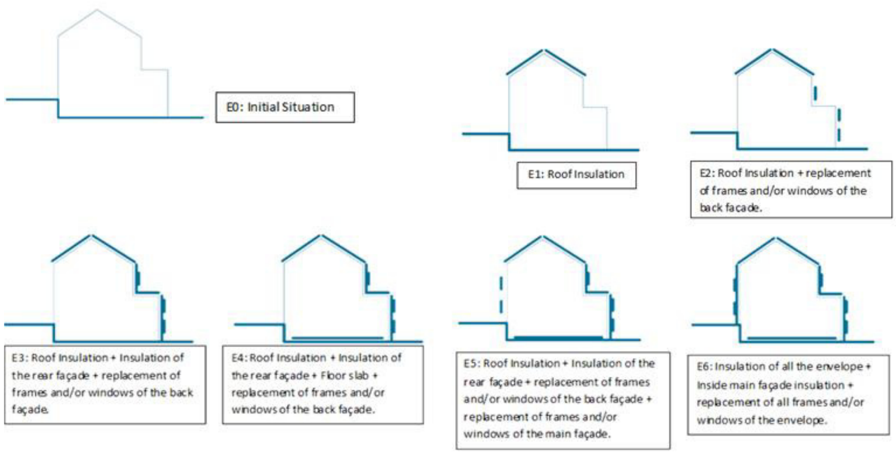


Fig. 8. Scenarios of envelope retrofitting

The scenarios for the retrofitting of the services are proposed in the same way, taking into account the existing technical services and the possible densification of the dwelling. The scenarios proposed improve strategies for existing technical services that include electricity generation, heat generation, hot water storage, heat distribution, lightning and ventilation.

All the possible scenarios defined are explored individually and in relation with the other scenarios. As aforementioned, the target is to deliver a full picture of the retrofitting process and that means to take into account that the intervention in one of the components impact in the others in one or other way. By coding these impacts by the traffic light colours we can deliver a schema of the elements we have to include in our intervention to achieve the expected energy efficiency outcomes (Figure 9).

This retrofitting guide sheets could be consider as a risk analysis of the interventions catalogued by element that shows the problems that could create to work in the building in a fragmented way.

Fig. 9. Retrofit guidance sheet

All the previous databases are included in the TCS matrix and represent the basis of its working methodology.

4. Future implementation

The final tool presents multiple ways of implementation: the first one is the scope of the project. Due to the large number and different typologies of the buildings in Brussels, the case study has been restricted to those of a much defined period and typology. The methodology to create the databases allows, however, the implementation of the formers.

Some assumptions have also been done in the measures for the retrofitting. Only those related with ventilation and heating has been taken into account. As well, in the retrofitting scenarios, not all the possibilities of occupation have been taken into consideration.

Finally, some improvements would be done to the tool in regards to its calibration. Till now, as aforementioned, the scenarios are based on a literature review on the studied building stock, investigated through best practice examples, industry overview and experience with refurbishment specialists. These scenarios will be enriched with the possibility to have reliable data in the behaviour of old mass masonry walls by working in the Energy House of the University of Salford. The data drawn from the 1:1 scale model of an old mass masonry wall house built by the

School of Built Environment in a controlled environment, would be include in the tool as to calibrate the validity of the results.

5. Conclusions

The paper presents a methodology to approach the retrofitting of the built environment by the definition and analysis of the existing dwelling typologies and their components.

By integrating this assessment of the existing built environment with strategies for its retrofitting, the research explores to increase the guaranties of success since the design phase. By addressing the problem from different axes and including the heritage value and identity of the building, the research will provide a retrofitting roadmap for the ancient building stock of Leopold Quarter in Brussels to meet the energy performance of buildings directive standards while preserving its heritage value.

The outcomes of the research will be gathered in a common database that would have the form of a tool. This tool is oriented to the design professionals so they can have an overview of the integrated strategy based in the quantification of the energy efficiency upgrade, cost optimal energy performance and heritage value preservation.

Acknowledgements

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