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Maturity Matrix Assessment: evaluation of energy efficiency strategies in Brussels historic residential stock

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Abstract

Energy retrofitting of historic or existing buildings is a challenge that it has not yet been properly fully addressed. Multiple projects and methodologies are published every day but neither of them with the holistic approach that will assure complete success since the design phase. This stock is never considered as a whole. Its components are installed, serviced and maintained by different companies and in different stages without a holistic approach to the overall building operation. The result is a lack of energy efficiency and feedback of the solutions implemented once the buildings are refurbished. Nevertheless, existing buildings play a key role in the achievement of the ambitious energy saving and greenhouse gas reduction targets that Europe has fixed for 2020 and 2050. Research has demonstrated that the impact in terms of decrease of energy use and CO₂ will be strong, considering that, in Europe, 80% of the 2030 building stock already exists and 30% are historical buildings. To achieve these goals, reliable data about energy consumption, building components and systems performance of the existing building stock is needed.

This paper presents a pre-assessment methodology to tackle the energy retrofitting of historic and existing residential buildings based on the Maturity Matrix Assessment. The maturity of the implementation of energy efficiency measures in Brussels historic residential stock is evaluated to determine future appropriate implementations. The matrix synthesizes appropriate strategies for this specific stock and provides a global map of the problematic, requirements and solutions.

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Nomenclature

BCR	Brussels Capital Region
EC	European Commission
EPB	Energy Performance of Buildings
EPBD	Directive on Energy Performance of Buildings
EU	European Union
GHG	Greenhouse Gas
H2020	Horizon 2020, Framework Programme for Research and Innovation
MMA	Maturity Matrix Assessment
PEB	Performance Énergétique des Bâtiments

1. Introduction

Buildings are at the centre of our social and economic activity. The built environment is not only the largest industrial sector in economic terms, it is also the largest in terms of resource flow [1]. Buildings are intrinsically linked to European societies, economies, and their future evolution. Energy security and climate change are driving a future that must show a dramatic improvement in the energy performance in Europe buildings [2].

The 28 European Member States have set an energy savings target of 20% by 2020 and 80-95% greenhouse gas (hereafter GHG) emissions reduction by 2050 as part of the roadmap for moving to a competitive low-carbon economy in 2050 [3]. The building sector is the highest energy consumer in the European Union (hereafter EU), with about a 40% of the total final energy consumption [4], and main contributor to GHG emissions with about a 36% [5] of the EU total CO₂ emissions what identifies it as a major contributor to the achievement of those goals.

In the Energy Efficiency Plan 2011 [6], the European Commission (here after EC) states that the greatest energy saving potential lies in buildings. The minimum energy savings in buildings can generate a reduction of 60-80Mtoe/a⁴ [7] in final energy consumption by 2020, and make a considerable contribution to the reduction of GHG emissions.

Moreover, the annual growth rate of new buildings is currently estimated at around 1-1.5% [8] while the number of buildings removed from the stock is about 0.2 – 0.5% a year [9]. This means that the 80% of the 2030 building stock already exists [10]. Hence, it is the older buildings, representing the vast majority of the building stock, which are predominantly low energy performance and subsequently in need of renovation work.

This study addresses the historic buildings – those built prior to 1945 -- and, in particular, those devoted to housing. In fact, the residential stock is the biggest segment with an EU floor space of 75% of the building stock. However, the energy performance of dwellings is generally so poor that the levels of energy consumed place the sector among the most significant CO₂ emission sources in Europe. It is clear that these buildings are in general not energy efficient and are substantial contributors to GHG emissions and rising energy bills. At a time when climate change poses a real and urgent threat to humanity and its infrastructure, it is vital to initiate an improved approach to the refurbishment of historic housing, which in many cases are in danger themselves [11]. Currently, the number of refurbishments accounts for roughly 2% of the housing stock and only a 5% of heating systems replaces a year [9]. This rhythm is not sufficient to reach the energy saving deadline.

On the other hand, one of the main problems encounter while studying the approach to the retrofitting of historic buildings is the lack of understanding of the current building stock. Fragmental approaches are promoted over global vision what produces strong discrepancies between the calculated and the expected outcomes by not taking into consideration interactions between the different strategies. Retrofitting buildings one by one will never solve climate change problems. Moreover, residential buildings are never considered as a whole. The result is a lack of energy efficiency, and in some cases functionality, once the buildings are refurbished.

Finally, there is a lack of data on the building sector what supposes a major obstacle to take the right decisions over a specific building stock and, even, to develop policies. In the case of the European building stock, “*for strong policy making at EU and member State level, it is key to establish an efficient monitoring system assuring good data availability and data quality*” [2].

Brussels, although having one of the richest and oldest architectural heritage in Europe, have an important lack of knowledge about the behaviour of its historic buildings. The literature on energy retrofitting strategies results very poor and there is no data available to track the retrofitting of existing buildings. The EPB (*Certificat PEB* in French) lists are not publicly available and there are not even accessible in one common place what makes hardly impossible to have a whole view of the current situation of the stock.

The aim of this paper is to present a methodology to evaluate the maturity of energy efficiency implementation in Brussels Capital Region historic housing stock. The presented methodology would ideally be implemented based on a questionnaire that would allow having a global vision of the stock and of some particular cases. However, due to the lack of real measured data, the approach will be to work with the data provided by CERAA's (*Centre d'Etude, de Recherche et d'Action en Architecture*) 2008 study that linked building typology and energy consumption [12]. Assumptions will be made based on these data to provide a preliminary assessment.

2. Brussels Historic Residential Stock: assumptions and constrains

2.1. Describing the problem

'If the building sector is to significantly contribute to the 80-95% GHG reduction target for 2050, each building, on average, will have to demonstrate very low carbon emission levels and consume very low energy in the context of a decarbonised power sector. For most of Europe's buildings, that probably means improving the current average energy consumption by a factor four or five and the installation of renewables. For some it could even mean a factor 10 improvement. This may be hard to imagine but is definitely doable' [13].

Brussels has a broad building heritage with buildings that largely pass 300 hundred years old. It is defying for this ancient patrimony to fulfil the energy consumption requirements allowing major renovations for the installation of renewable energy systems while conserving its heritage.

In September 2013, APUR [14] raised 5 points of awareness in the works and the approach over Brussels historic buildings: (i) there is not real data about energy consumption: They recommended a large scale and in-depth study to have a broad knowledge of the consumption behaviours; (ii) the recommended performance levels this stock need to reach, have not been fixed with a knowledge of the pathologies that the measures could cause in the building in the long term. This is due to a lack of monitoring of previous interventions; (iii) there is a lack of knowledge transfer between the agents which results in deficit of know-how about the specificities of this stock and the impact of the implementation of different measures; (iv) there is a lack of feedback among the work itself since the design phase to the completion of the works; (v) finally, the recommendations and aid renewal mechanisms are attributed independently of the building nature. Independent of any consideration of the masonry typology. This could lead to unbalance the thermal levels. These issues are still unsolved.

2.2. Objectives

The project has been conceived to define a holistic methodology to support the lifecycle of the retrofitting of Brussels historic housing. It aims to achieve the following objectives:

- Identify suitable energy efficiency strategies for this building stock;
- Assess the maturity level of the building stock or class at a given moment of time;
- Support the definition of the target levels to achieve in a given retrofitting;
- Define the roadmap evolution for a building or class to achieve specific targets.

The final result of the project will be an implementation plan detailing the activities to perform.

2.3. Building Typologies

Brussels has a heterogeneous and rich stock of residential buildings. Some of them dating from before 1900. These 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. The scopes 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 [15].

Several projects have worked in the definition of Belgium building stock [16] in the frame of European housing stock. Common spatial definitions were used to be able to compare their construction systems, technologies and consumptions. These catalogues have been reused in some European projects as the basis of the definition of strategies [17] to tackle them. CERAA [14] has developed one of those studies over the specific Brussels housing that is used as the cornerstone of the study. Although some assumptions were done in the definition of the stock, the study is able to provide a broad view of the existing building typologies and their energy consumptions. It catalogues the building stock based on two main characteristics: situation in the urban fabric (terraced house, semi-detached or end terraced, detached and apartment buildings) and construction year.

This paper focuses on those buildings constructed prior to 1945 although Table 1 shows the complete dataset. This allows having a glance of the impact of this specific part of the stock in the overall.

Table 1. Heating Consumption by m² (kWh/m²year) Source: CERAA [18]

Building Typologies	< 1919	1919 - 1944	1945 - 1970	1971 - 1980	1981 - 1990	1991 - 2000	2001 - 2006	Total by typology
Terraced House	147	151	162	113	113	113	113	151
End terraced and semi-detached house	174	169	182	127	127	127	127	170
Detached House	176	181	195	136	136	136	136	180
Apartment building	146	151	162	113	113	113	113	145
Total by age	152	156	167	115	117	115	115	153

3. Methodology: Maturity Matrix Assessment

A Maturity Grid, or Maturity Model, is a management assessment tool developed for evaluating an organization's level of progress towards a goal. The grid, which is a matrix laid out in rows and columns, lists the criteria that will be evaluated. Each column's corresponding row has cells that describe the typical behavior exhibited by an organization at each level of development. Maturity grids can be used to provide an organization with an initial benchmark for how close to 'fully developed' is in regards to the criteria being assessed. They are also useful tools for leading discussions and providing management with roadmap for next steps. This tool, largely used in business sector, is not yet common among the building stakeholders.

When searching for a methodology that could help to assess the current state of Brussels historic housing stock and provide a broader vision of the path to achieve the goals, the maturity grid seems to check all the boxes. Based on this business-born tool, the specific model developed for this study was named Maturity Matrix Assessment and it was bespoke designed to fulfill the requirements of the built environment professionals. Although it is well recognized the utility of this tool, only few interesting examples could be found in the maturity assessment of Building Information Model (BIM) systems and in construction processes [19-22]. As a result, the Maturity Matrix Assessment is defined in this study as an analytical methodology that seeks to provide optimal strategies for the retrofitting of a given building or building stock [23]. This methodology requires a thorough understanding of the building nature [24]. Once the targeted building stock is selected, the continuous feedback schema depicted in Fig. 1 is activated to process all these buildings. This schema relies in two support components: a questionnaire to facilitate data retrieval and a maturity grid that define a set of indicators to assess maturity.

The questionnaire is a definition tool that could be done based in available data, when is for the definition of a building stock, but that could be developed together with the client. This last option, that could include the possibility

to do some testing and measurements in the targeted building or stock, will provide the necessary data to define the retrofitting strategies levels of the matrix. The present study has been conducted following the first approach.

All answers to the questionnaires, once integrated in the matrix, result in a clear understanding of the current level of maturity in the implementation of energy efficiency solutions. The outcome is presented in the form of a Maturity Assessment roadmap to achieve the previously defined energy efficiency goals.

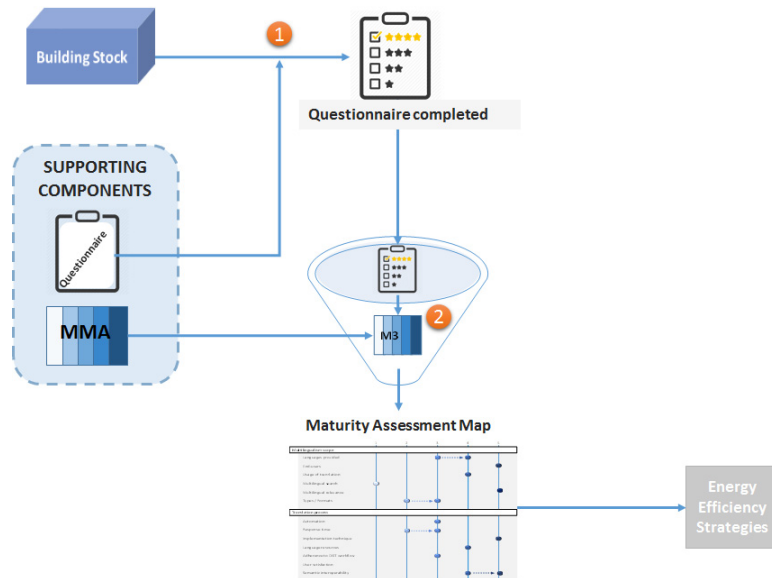


Fig. 1. Maturity Assessment Methodology

The matrix is composed by a set of indicators that are scored with values from one to five depending on the maturity (Fig. 2). In this case, the indicators are grouped in the so-called scopes: thermal performance of building fabric, ventilation, heat sources and electricity sources. For the definition of the different maturity levels by indicator, several studies have been taking into consideration to identify pertinent strategies related to the retrofitting of historic buildings and evaluate its relevance. The most remarkable study is the work of Thaleia Konstantinou [25] as it provides specific measures linked to construction specificities of the stock. She has also calculated the U-values resultant of the application of each measure what would help in further steps to have an overview of the energy consumption attached to the maturity level of the stock.

A name convention is developed in order to simplify the denomination of the stock status before and after the implementations. The “AS-IS” name is given to the current situation of the building, as well as the “TO-BE” is to the optimized proposal. Hence, the questionnaire and the matrix are used to define, not only the state-of-the-art of the building stock, but also to define the target level of each indicator. The target level depends on the indicator and the level of improvement that could be achieved, sometimes linked to a cost-optimal solution. It means that the target level for some indicators could be the maximum (5) but for others would be lower (3-4).

The combination of “AS-IS” and “TO-BE” in the same chart allows to have the holistic vision that commonly lacks when approaching the retrofitting of an historic building. It also allows to avoid overlapping of strategies that would not arrive to achieve the expected improvement outcome. This chart is subsequently represented in a map, namely Maturity Map (Fig. 3). The Maturity Map displays the indicators involved in the transformation process and all transformations required by indicator. The transformation for a given indicator could be done in several steps (see 3 in Fig. 3), or in one step (see 2) depending on the necessity of the implementing action.

The final step of this process is to include a transformation planning. Thus, the critical path to achieve the objectives is transform into a real implementation planning and a set of actions. Architects and urban planners could, therefore, perform estimations of cost and time of all the activities and prioritize their execution accordingly.

Indicators	Description	Maturity levels								
		1	2	3	4	5				
Scope 1: Thermal performance of building fabric	Wall insulation	Integration of insulation materials in the building envelope. Depending on the nature of the building and its historic protection, this insulation could be implemented in the external or internal face of the main facade or in the rear facade.	Masonry of solid brick or stone, 250-400mm/ Two leaves of masonry with intervening air cavity. Loadbearing walls. Inadequate thermal resistance.	Use of foam insulating material in the existing cavity between inner and outer wall leaf. Increases thermal resistance. Performance depends on existing cavity depth.	Insulation on interior wall sheathing with plaster or plasterboard. Increases thermal resistance to required level.	Rigid insulation boards on exterior of wall sheathing with plaster. Increases thermal resistance to required level.	Rigid insulation boards on exterior of wall, with panel for finishing. Substructure for the panels needed. Increases thermal resistance to required level.			
		Ground floor insulation	Integration of insulation materials in the floor element. Different situations could be addressed depending the nature of the floor: in direct contact with the soil, internal dividing floors,	Basement unheated. Concrete slab or wooden beams construction. No insulation; reinforced concrete slab or wooden beams construction. Heat loss from first floor through basement ceiling.	Little/Outdated insulation: Reinforced concrete slab or wooden beams construction with 20-40-50mm insulation on top. Heat loss from first floor through basement ceiling.	Insulation on top of the heated floor slab. Increases thermal resistance to adequate level.	Insulation under first floor slab. Increases thermal resistance to adequate level.	Additional floor - occupied basement. Basement heated. Insulating basement floor and walls advised.		
			Roof insulation	Integration of insulation materials in roof and/or loft.	Pitched roof: timber rafters no insulation; rafters, sheathing, counter battens, roof covering, plaster-covered, and no insulation in cavity. Inadequate thermal resistance.	Little/outdated insulation: Plaster, 130-150mm reinforced concrete slab 20-40mm insulation, screed. Inadequate thermal resistance.	Pitch roof insulation: Insulation between rafters. Jling. Increases thermal resistance to required level. Advised for heated attic.	Insulation of top floor slab. Insulation on attic floor. Advised for unheated attic. Prevents heat loss through top floor slab to unheated attic space.	Flat roof: Additional insulation on roof slab, waterproofing. Increases thermal resistance to required level.	
				Upgraded/replace Windows	Replacement and tightening of windows	Single glazed windows panes, g&0.87 (Ug<2.5). High heat losses.	Double glazing applied on existing window frame. Increases thermal resistance of window pane.	Secondary single glazing window pane. In the inside. Creates thermal buffer. External appearance unchanged.	Replace the existing glazing and frame with 5-or-A double-glazing resistance and air-tightness.	Replace existing glazing and frame with triple-glazed windows
					Doors	Replacement and tightening of doors, internal and external.	Solid single layer wood door	Reinforced security door double layer wood exterior door	Door draughtproofing	High performance doors
Scope 2: Ventilation	Ventilation	Supply of air by natural or mechanical means to the interior of the building	Natural Ventilation: Air movement through the facade's openings, driven by the climatic forces. Exchanges the heat internal air with cool outside air. Cooling effect	Background ventilators and intermittent extract fans: Air is extracted from the building by fan devices, ducts and roof/wall outlets.	Mechanical Inlet/Natural Exhaust: Air is supplied to the building by fan devices, ducts and roof/wall outlets.	Mechanical Ventilation: Air is supplied and extracted from the building by fan and using exhaust air terminal devices, ducts and roof/wall outlets.	Ventilation system with Heat recovery (HR): Heat exchangers heat or cool incoming fresh air, recuperating 60 to 80% of the conditioned temperatures.			
		Scope 3: Heat sources	Heating	Generate heat of/and hot water for hydropic heating systems and DHW	Fossil fuel boiler: Transfers the heat liberated during combustion into the heating system	Replace existing boiler in each dwelling. High efficiency. Transfers the heat liberated during combustion into the heating system. Efficiency >90%	Heat pump system to transfer heat from the source by means of electrical or thermal energy at a high temperature to the heat sink.	Biomass boiler: Transfers the heat liberated during combustion into the heating system, using biomass fuel	Solar Thermal: Convert direct solar radiation into thermal energy	
Scope 3: Electricity sources	Electricity			Generation of Electricity by different means	Fossil fuels: Gas or Coal	CSP installation: Provide simultaneous generation in one process of thermal energy and electrical and/or mechanical energy.	Photovoltaic panels: Convert direct solar radiation into electrical energy.	Small wind generators:	Hydropower generation: produces between 10 and 100 times more power than PV or wind for the same capital investment. Provides lots of off-grid energy for a long time. No need or very low need for energy storage.	

Fig. 2. Maturity Matrix

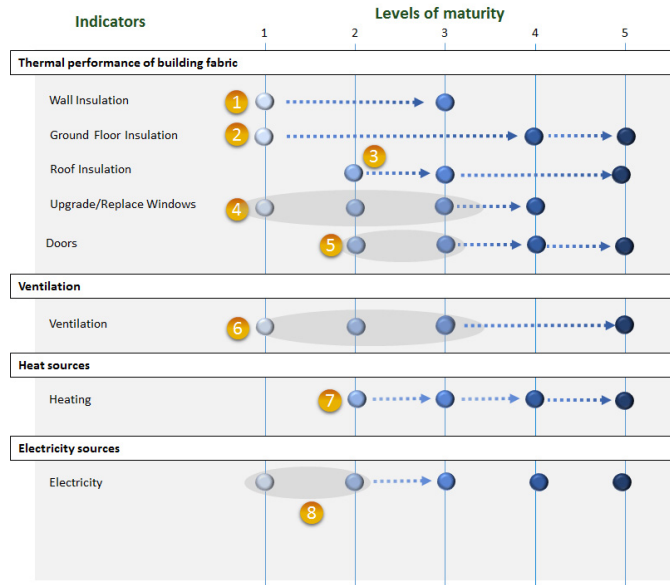


Fig. 3. Maturity Map

During the execution of the transformation plan, the maturity level should be re-assessed to ensure that indicators are evolving as planned. This “dynamic” view of the evolution plan makes the Maturity Map also a monitoring tool on the evolution of the maturity towards the plan.

4. Results

Fig. 3 shows the first results of the application of the Maturity Matrix Assessment in the Brussels historic (pre-1945) building stock. It consists in a Maturity Map that depicts both the maturity of the housing stock and the evolution they should face in the future to achieve the energy savings and GHG emissions reduction targets.

The current maturity level of most indicators is mainly in the range 1-2 as summarizes in Table 2, what entails a low maturity level in general. This table offers the global vision of the current situation of the housing stock (AS-IS), as well as the minimum level to achieve the targets (TO-BE minimum target) and what has been considered the optimal level of implementation (TO-BE optimum target).

Table 2. Maturity Map results by indicator

Indicator	AS-IS	TO-BE (minimum target)	TO-BE (optimum target)
Wall insulation	1	3	3
Ground floor insulation	1	4	5
Roof insulation	2	3	5
Upgrade/replace windows	2	4	4
Doors	2.5	4	5
Ventilation	2	5	5
Heating	2	3	5
Electricity	1.5	3	3
Average Maturity Level	1.8	3.6	4.4

These two levels of implementation come from the literature review of other studies over the European building stock that demonstrates that the optimum-cost situation could be achieved better in two-steps retrofitting process [26]. This procedure has been followed in the vast majority of indicators.

The average maturity level of the existent housing stock of all indicators in the “AS-IS” is 1.8. This maturity level is considered as the as-built configuration for this building stock. As-built means, therefore, a configuration with a maturity level halfway between levels 1 and 2. This configuration has three indicators below the average maturity: Wall and Ground floor insulation (with the minimum level) and Electricity. Fig. 3 shows that in the case of Electricity there is not only one “AS-IS” score but two as the housing stock does not show a common standard. The main solutions implemented in this type of housing is based either in fossil fuel or CHP installations, which scores respectively with the lowest scoring in this indicator. Doors, ventilation, heating and windows have the higher scores in the as-built configuration. This could be related to the fact that those elements either receive incentives in the form of subsidies provided by public institutions for their improvement or are those elements with a lower cost of implementation related to the outcomes.

In the case of the “TO-BE” minimum target, the maturity achieved scores 3.6, what means to have a minimum maturity level in all indicators equal to 3, what doubles the “AS-IS” score. The minimum configuration for the targeted building typology (residential building built before 1945) is focused in the improvement of internal wall, ground and roof insulation, the substitution of single glazing by double-glazing-windows, the improvement of the air tightness with a draught-proofing door, the inclusion of a ventilation system with heat recovery, and the installation of a heat pump and photovoltaic panels. These implementations are the most cost-effective of those proposed as it could be observed when re-assessing the maturity and obtaining a high maturity level (3.6). Moreover, these improvements are main subsidies target in Brussels.

The transformation to attain the optimal configuration affects to only four indicators, as the “TO-BE” minimum and optimum targets are the same in four of the indicators. The optimal configuration scores 4.4 with 5 indicators reaching the maximum maturity level (ground floor insulation, roof insulation, doors, ventilation and heating) and three reaching a level 3 (wall insulation and electricity). The case of electricity is paradigmatic as with only achieving level 3 the minimum and optimum targets are met. However, progressing to level 4 or 5 have not considered as optimum as the application of these 2 renewable energy solutions has not been sufficiently explored at the housing level and, albeit their outcomes are interesting for the improvement of energy efficiency, their deployment is constrained by multiple factors.

Resuming, the “TO-BE” optimum target involves an evolution of the “TO-BE” minimum configuration with the implementation of the following solutions: heated basement, additional insulation in the roof, high performance door and solar thermal heating. The achievement of the optimum and minimum levels depends, in some cases, on the budget available. This is the case, for example, of the roof additional insulation. Although a high insulation level appears to be an energy saving solution it could jeopardize the good behavior of an ancient structure because of lack of ventilation and excessive air tightness. These type of decisions are key during the phase, as further changes in the house configuration does involve a double investment that it might not be justified if we consider the real benefits in energy consumption obtained.

5. Conclusions

The analysis presented in this paper aims to raise awareness on the achievement of H2020 targets and proposes a methodology to analyze the building stock as a whole to support the progress as a transformation process. The approach is based on the definition of a set of relevant retrofitting strategies applicable to the different building components so that more mature solutions corresponds to higher maturity levels.

The methodology has been customized to the showcase of the Brussels Capital Region historical residential building stock. This customization consists in setting the so-called Maturity Matrix with those solutions that are specifically designed to improve this building stock. This approach facilitates the re-usability of the methodology for other building typologies. The development of this showcase highlights that an in-depth analysis is needed to identify adequate solutions applicable to the historic housing typology what will later contribute to the successful improvement of their energy efficiency. This identification is also essential to reap the benefits from the design phase. The main

difficulty found in this study is the scarcity of data available to conduct such analyses in certain building typologies. Few projects to measure the consumption have been carried out in this stock and the renovation works that are commonly carried out do not respect the original layout. As a result, this study has dealt with those data leaks by making specific assumptions that could, somehow, hinder the conclusions.

This study concludes that the maturity of the housing stock is below the level it was supposed to be in 2016 to fulfil on due time the H2020 targets. The maturity level of the building stock today is halfway the achievement of the objectives with a maturity level of 1.8 while the target would be 3.6. There is a long way ahead if the renovation ratios continue as they stand. The achievement of the targets requires the involvement of public institutions to boost the refurbishment of building stocks instead of a building-by-building approach.

The maturity matrix assessment defined emerges as a valuable analytical methodology to support the retrofitting process as a whole. Indeed, it could be considered as a sort of change management tool that supports the transformation of the building stock since the conception until the execution. It helps outlining the transformation process to be carried out into a transformation planning that could be used to track the evolution of refurbishment. The maturity level could be, therefore, assessed at the beginning of the transformation, during the execution and at the conclusion, so it offers a reliable picture on how it is progressing that will trigger corrective measures when a deviation with the schedule is identified.

6. Further steps

The goal of this paper is to describe the methodology defined to assess building stocks and to present the first results of the application of such methodology to the case of the historical building stock in Brussels Capital Region. The evaluation of the building stock has been done, for some indicators, using data produced in other studies. However, those results have been obtained based on specific assumptions. Those assumptions would be re-assessed to ensure the accuracy of the results published during the year.

The second aspects that deserves further effort is to test the methodology with other showcases. This could be done either by extending of the scope of the assessment to further building typologies or to involve other cities. The former will be used to determine the level of granularity of the data that will be managed by the methodology, while the latter will assess the feasibility of using the methodology in other scopes. These two elements together will be used to consolidate the methodology.

Finally, specific actions would be carried out to disseminate the results of the study and the methodology with the research community and with public institutions that could be interested in their application. The dissemination is not limited to Brussels but it would involve other cities with interest in retrofitting of historical buildings. Those cities could easily adopt not only the methodology but also the matrix indicators and the definition of the maturity levels.

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