

A Façade Refurbishment Toolbox Supporting Energy Upgrade of Residential Building Skin

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Summary

Over the next decade investments in buildings energy saving need to increase, together with the rate and depth of renovations, to achieve the required reduction in buildings related CO₂ emissions. Although the need to improve residential buildings has been identified, guidelines come as general suggestion that fail to address the diversity of each project and give specific answers on how these requirements can be implemented in the design. During early design phases, architects are in search for a design direction to make informed decisions, particularly with regard to the building envelope, which mostly regulated energy demand.

To result into a sustainable existing residential stock, this paper proposes a methodology to support refurbishment strategies design. The result or the proposed methodology enables designers to make informed decisions that generated energy and sustainability conscious designs, without dictating an optimal solution, from the energy point of view alone. Its applicability is validated through interviews with refurbishment stakeholders.

Keywords: Refurbishment, residential energy upgrade, design process

1 Introduction

The motivation to improve existing buildings lays in society's efforts for sustainable development. The required reduction in buildings related CO₂ emissions reaches up to 90% by 2050, indicating the building sector's importance and the urgency for measures uptake. Over the next decade investments in buildings energy saving need to increase, together with the rate and depth of renovations [1]. The domestic sector can potentially make a significant contribution to reducing energy consumption [2]. Additional studies have shown that households have larger energy saving potential and benefit than other sectors, along with the necessary higher investment [3]. Moreover, residential buildings account for 2/3 of building floor area, while the condition and efficiency of a large part of the residential stock still needs attention.

Since the need to reduce the energy demand of the residential building sector is urgent, the efforts must focus on the existing buildings. While new constructions add annually 1% or less to the existing stock [4-6], the other 99% of buildings are already built and produce about 24% [7] of the energy-use induced carbon emissions. Residential buildings account for 70% of building floor area [8], while the condition and efficiency of a large part of the residential stock still needs attention. On the other hand, demolition is not the solution. Regarding materials and waste, studies show that the environmental impact of life cycle extension of a building is definitely less than demolition and new construction [9]. However, buildings suffer from a variety of physical problems. Taking into account that the expectation for the structural life of a building often exceeds 60 years, while the envelope shows signs of obsolescence after only in 20 or 30 years [10, 11], it is understandable that the residential stock is in need of refurbishment.

Although the need to improve existing residential buildings has been identified, guidelines come as general suggestion that fail to address the diversity of each project and give specific answers on how these requirements can be implemented in the design. The integration of all design aspects during the early design phases is complex. At this stage, the architects are in a constant search for a design direction to make informed decisions [12], particularly with regards the building envelope, which is the most influential to energy consumption. The energy

need for heating and cooling of buildings is directly related to heat losses through building envelope components, such as external wall, windows, roof and ground floor, ventilation and air infiltration and inversely related to heat gains in the building through solar radiation.

To result into a sustainable existing residential stock, this paper proposes a methodology to support refurbishment strategies design. In the first part, refurbishment design process is analysed and a methodology to integrate the energy saving potential into the design is proposed. The methodology called “façade refurbishment toolbox approach” is based on compiling and quantifying retrofitting measures that can be also seen as “tools” used to upgrade the building’s energy performance. Subsequently, the effect of each measure is quantified. The building performance is assessed in terms of energy efficiency. The result or the proposed methodology enables designers to make informed decisions that generated energy and sustainability conscious designs, without dictating an optimal solution, from the energy point of view alone. Its applicability is finally validated through interviews with refurbishment stakeholders.

2 The Design Process

Achieving energy savings in buildings is a complex process. Reducing the energy demand requires the deployment of effective solutions which in turn makes it necessary to understand what affects people’s decision-making processes [1]. In order to systematize the decision-making process, researchers have identified different phases in the design and execution of refurbishment strategies. Ma et al. [13] reviewed the main phases of a sustainable refurbishment program and identified five steps, starting from the project setup and pre-refurbishment survey and ending with validation and verification of the refurbished building. Similarly, Ferreira et al. [14] define five steps that include definition of refurbishment scope, diagnosis real building’s conditions, identification of alternative scenarios according to client’s choices, technician’s experience etc., assessment of the scenarios and optimization. These stages are present not only in the case of refurbishment, but the construction process in general. Cooper et al. [15] set up a process protocol model that breaks down the design and construction process into 10 phases that can be grouped into four broad stages; pre-project, which includes determining the need for the project solution, pre-construction, when an appropriate design solution is developed, construction, which produces the project solution and finally post-construction, which aims at monitoring and maintenance of the project.

Based on literature and experience with refurbishment stakeholders, refurbishment design and construction process have been divided in the five phases, shown in Figure 1 **Fehler! Verweisquelle konnte nicht gefunden werden.** The phases described are typically encountered, but variations are possible. There are cases where a more interdisciplinary process was followed. The design team consists of different experts from the early phase, which blurs the boundaries of which decisions and evaluations were made in each phases. Nevertheless, the phases are considered indicative both in interdisciplinary design teams or more traditional team composition.

Refurbishment project starts with the pre-design, which is Phase 1. This is when the requirements that the refurbished building need to fulfil are defined. It begins with identifying the need to intervene, which then initiates the refurbishment project. The building owner typically makes the decision, according to regular refurbishment cycles, as well as reported problems and users’ dissatisfaction. Subsequently, the specific requirements of the project are set. Requirements are formed by the building owner, typically a house corporation or individual homeowners, often with the involvement and advice of architects or other experts.

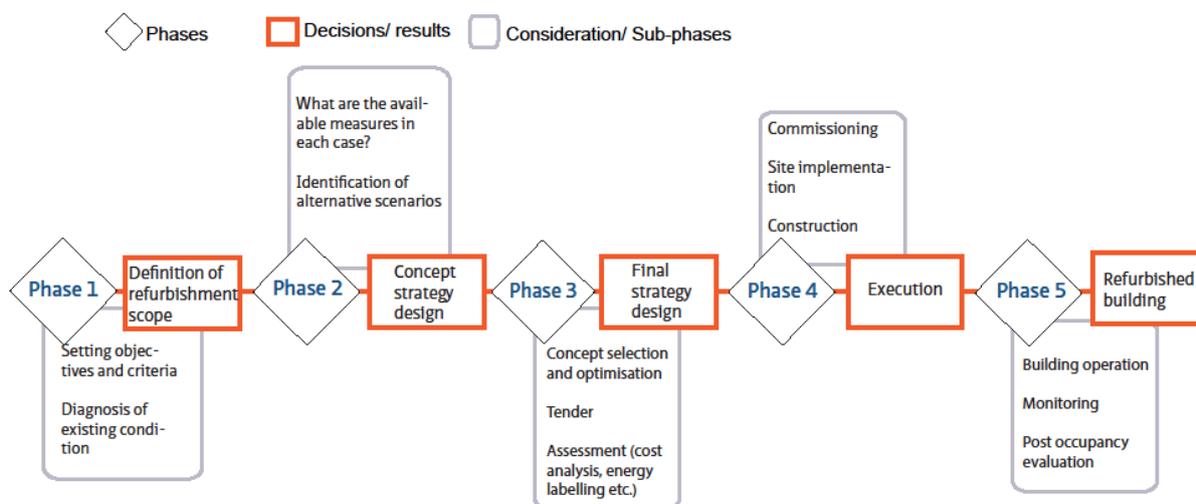


Figure 1: Scheme of the design process phases

After the requirements for the refurbished building have been established, the design stage begins. More than 80% of the building performance, both in terms of energy savings, generation, and cost, is set during this stage [16]. The design can be divided in two phases: the concept and the final design. During the concept design (Phase 2), the team looks at the possible measures to implement and identify possible scenarios, which are evaluated in order to select the scenario to be further developed in the final design phase. The scenarios and the decision that shape the strategy are typically developed by an architect, who has to take in to account the parameters defined on the previous phase such building programme, architectural qualities, and depth of refurbishment. At this stage, the architects search for information to support the design direction [12]. An evaluation is needed to support the decision-making, when various scenarios are discussed. The evaluation concerns the performance in general, such as energy, comfort, spatial and aesthetical benefits, together with investment aspects. The final design begins after the design team has chosen the strategy concept (Phase 3). It includes the optimisation and assessment of the selected concept. The assessment of energy use, often in the form of energy certificates, occurs at this stage.

When the design has been finalised and the assessment has resulted in the desired performance, the execution phase comes. It refers to the realisation of the designed intervention, which is the construction on the building site, including demolition of components to be replaced, fixing of damages, acquisition and installation of new components and material etc. Finally, the execution (Phase 4) results into the refurbished building and the last phase of the project, which is the operation by the users (Phase 5).

The interest of the present thesis lies on the first three phases, as they are more influential for the building energy upgrade. Requirements for energy performance are normally already set in Phase 1, the pre-design phase. The assessment, however, often happens in Phase 3, when the different options have been investigated and the design is being finalized. To determine the energy performance of a building, architects typically rely on the input of outside experts, which can slow down the design process [17].

Estimating the refurbished building performance is essential during the decision-making for refurbishment and there are already methodologies developed to make this estimation. Building Performance Simulation (BPS) computer software provides this opportunity. However only 1% of these tools is targeting architects during the early design phases, while architects consider these tools non-user-friendly and are reluctant to integrate them into the early design phase of high performing buildings. Decisions taken during this stage can determine the success or failure of the design [12]. Analysis of some tools has identify as problem the level of performance

feedback in relation to a specific design phase [17], as they are often used for post-design evaluation [18]. There is a need for decision support tools that integrate energy simulation into early design in the architectural practice.

3 The toolbox approach

Information to support refurbishment decision-making often come in the form of general suggestion, which are not always easy for the designer to incorporate in the decisions. Moreover, some of the information target the occupants, owners and public authorities, who are parties that influence or even determine the decisions made, but do not actively participate in the actual designing of the strategy. To improve these aspects, our approach focuses on the architect of refurbishment strategy that makes decision on the design quality. The developed approach is also referred as a “toolbox approach”, because the different retrofitting measures can be conceived as the “tools” that constitute the refurbishment strategy. In this sense, the organisation of the different measures compiles a “Façade Refurbishment Toolbox” (FRT), from which the refurbishment design selects the tools to use to upgrade the building envelope. In this paper, the compilation and quantification of the FRT, as well as its applicability, are presented.

3.1 Compilation of retrofitting measures

In order to be able to assess the energy performance of the refurbished building in the early stages of the design phase, refurbishment options have to be systematically organised. The options compiled aim at giving design solutions to upgrade the thermal envelope and translate the general design principles and performance benchmarks into specific retrofitting measures. After identifying the key components for an integrated refurbishment strategy, solutions are given for each one. The measures are state-of-the art refurbishment solutions being used in refurbishment. Different measures are proposed for each component, based on refurbishment practice and experience, as well as literature review of research projects on refurbishment, such as EPIQR [19], TABULA [20], SUSREF [21], IFORE [22], and other [23].

The compilation of the options of resulted in the Façade Refurbishment Toolbox. This toolbox is essentially a database of possible measures that can be implemented in refurbishment projects. The information is organised in a matrix, according to the key components of the building envelope, as presented in Table 1. The measures can be combined depending on the specific requirements of every project and design, resulting in the integrated refurbishment strategy. Addressing solutions for all the above composes integrated refurbishment strategies. The measures are scaled according to effort and level of intervention. In this way, each project can be located on the top, middle or bottom of the table according to requirements. Moreover, it is possible to combine various levels, for example apply a more complex solution for the wall and a simpler one for the rest of the components. Moreover, the toolbox matrix is organised according to the efficiency of the measure and the level of intervention, based on preliminary calculation [24]. This helps to easily identify the possible options depending on the projects ambitions and, thus, facilitate the selection.

3.2 Quantification

The toolbox approach aims at providing an assessment of refurbishment options impact on the energy performance of residential building. The goal of an integrated refurbishment is improving all components of the building envelope where heat losses occur; hence, the different retrofitting measures are presented according to the component they address. Apart from catalogue the retrofitting measures, information to evaluate and compare them is needed. To this end, the measures are quantified, according to the energy saving, in comparison with the existing building energy demand, prior to the measure application. To quantify this effect, dynamic simulation is used. The software used for the thermal simulation is DesignBuilder [25]. There is a wide variety of software for building energy analysis [26]. DesignBuilder was chosen as appropriate for the purpose of this study, because it can generate a range of environmental performance and it provides a modelling interface, integrated with EnergyPlus, which is the U.S. DOE building energy simulation program for modelling building heating, cooling, lighting, ventilating and other energy flows.

Table 1: The toolbox matrix

	Building envelope					Building Systems	
	Exterior wall	Window	Balcony	Roof	Ground floor	Ventilation	Heat source
Existing construction	Masonry/ cavity wall no insulation	Single glazing	Continuous slab, no insulation	Pitched roof, timber rafters no insulation/ occupied loft	Slab on ground, no insulation	Natural ventilation	Gas stove
	Lightweight concrete/hollo w brick, no insulation	Early, double- glazing	Separate slab no/little insulation	Pitched roof, timber rafters no insulation/ unheated loft	Basement unheated. Concrete slab, no insulation		Fossil fuel boiler in each dwelling
	Little/outdated insulation			Concrete slab, no/little/outdat ed insulation	little/outdated insulation	Trickle ventilation	Fossil fuel boiler per block
Retrofitting measures	Cavity insulation	Upgrade windows	Insulate balcony slab	Pitched roof, no insulation/ unheated loft	Insulation on top of ground/first floor slab	Natural inlet/ mechanical exhaust	Replace existing boiler in each dwelling, high efficiency
	Internal insulation	Secondary glazing single	Cut off balcony	Pitch roof insulation	Insulation under existing floor	Mechanical inlet/ natural exhaust	Replace existing boiler per block, high efficiency
	Exterior Insulation and Finishing Systems (EIFS)	Secondary glazing double	Balcony cladding - Single glazing	Insulation of top floor slab		Mechanical ventilation	CHP installation
	Ventilated façade		Balcony cladding - Double glazing	Flat roof		Ventilation system with heat recovery (HR)	Heat pump
	Timber-frame wall	Replace windows (Double pane)		Green roof			
	Second Façade/ Single glazing	Replace windows (Triple pane)					
	Second Façade/ Double glazing	Shading adjustable					Biomass boiler
	BIPV's			Photovoltaic			Solar collectors
	Added space/ Second façade integrated	Shading fixed	Integrated balcony				Geothermy
	Lift addition	Enlarged windows	New balcony	Additional floor/ occupied loft	Additional floor/occupied basement		District/ community heating

The assumptions used as input in the calculations were based on European standards, such as EN15251 [27]. They were regarding ventilation, heating and cooling user thermal comfort criteria, as well as values for internal gains and occupancy. Based on the inputs, the building thermal performance was simulated on an hourly basis, throughout the year and gave results on the energy demand of the modelled building and the internal temperature. The toolbox quantification aimed at results that can be comparable, the simulation settings were kept as much as possible fixed when simulating different measures. This means that the performance of each measure can be further optimised, if a high resolution simulation, to predict more detailed performance, was required. This was, however, beyond the scope of the approach.

The measures are quantified in terms of heating energy demand, which represents more than half of the final energy consumption of residential buildings in the EU is used for space heating, reaching up to 70% in some countries [1, 8]. This is the energy needed to balance the heat losses in order to maintain the required temperature. As a large part of heat losses are through the building envelope components, the retrofitting measures reduce these losses and, hence, the energy demand. Replacing the existing system with one of higher efficiency will result in additional savings in delivered and primary energy demand than the savings in heating energy demand already suggested by the toolbox calculation. To estimate the savings in primary energy, however, it is necessary to consider the fuel type or the energy mix, with the respective primary energy factor (PEF), as well as the system efficiency. This information is site-specific and cannot be generalised in the toolbox data.

To evaluate and compare refurbishment measures, each option needs to be quantified separately. Since this quantification is expressed as reduction in current energy demand, the method used to isolate the impact of each option has two distinct steps. First the existing building's condition was simulated, to determine the current energy demand and, subsequently, the building after the refurbishment measure application, to evaluate the impact on energy demand. The toolbox options calculations generated specific figures on energy demand reduction related to each retrofitting measure. The following figure presents an overview of the potential savings as an effect of the retrofitting measures application. However, these percentages can vary in buildings that differ in the characteristics such as construction, window-to-wall ration (WWR) and orientation. Based on the specific building characteristics, the FRT approach has available data that provides an indication of the measure effect, expressed in percentage of heating energy demand reduction compared to the current demand [28].

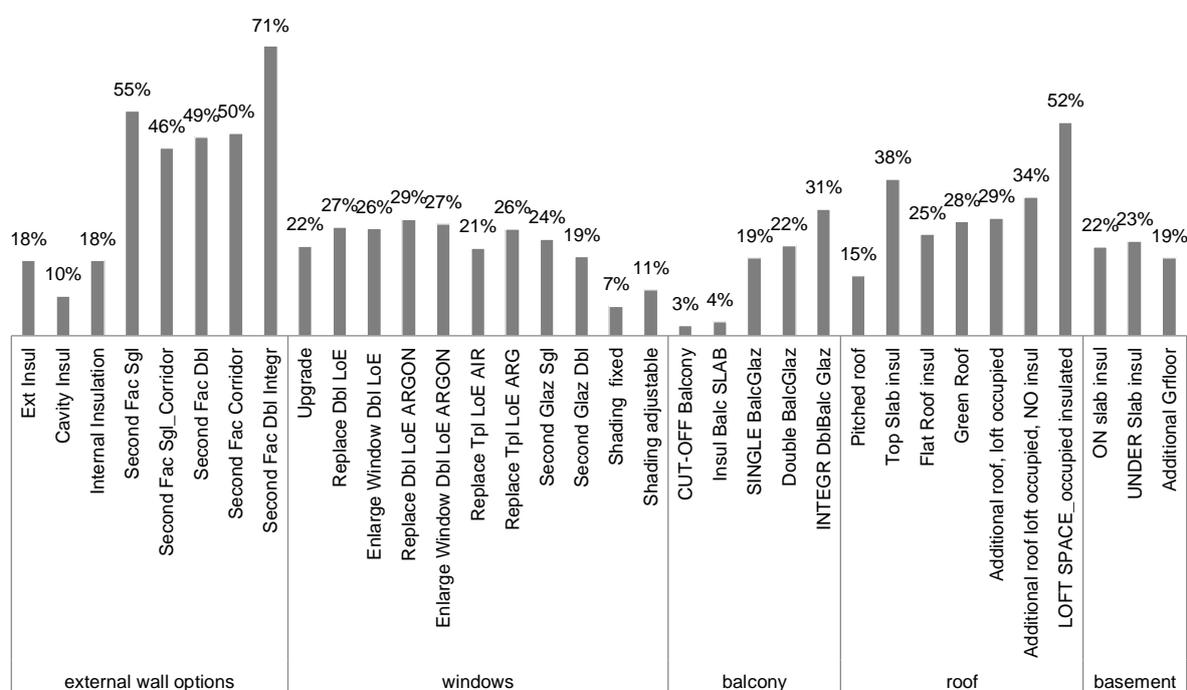


Figure 2: Overview of heating demand reduction after the application of retrofitting measures in the respective components. The values refer to typical apartment and they are average for different building types, WWRs and orientation.

3.3 Applicability

The toolbox calculation results can be used in refurbishment project, based on the existing building characteristics. The quantification of the measures is based on simulation of different building types before and after the application of a measure. The result is the percentage of reduction on the energy demand. In future projects, the building to be refurbished must be associated with the pre-calculated models according to each component construction, providing an indication of energy saving potential of different retrofitting measures without new simulations, to be support the early stages of the design.

Based on the pre-calculated models, the approach can provide percentages of energy demand reduction after the various measures application regarding each specific building. The steps to follow to obtain those data are shown in Figure 3. First, the existing construction, together with WWR and the façades orientation need to be identified. According to this information, the building can be associated with the pre-calculated model. Moreover, it needs to be determined whether it is relevant to look at the typical apartment or the whole building. In most cases, particularly in apartment building, the savings of the typical apartment are a better indication to consider in the decision-making, as the effect of the measure is greater than in other types. Nevertheless, depending on the building type and the objectives of the design team, the whole building consumption may be also relevant. Finally, the percentage of potential energy demand reduction for each component retrofitting measure can be obtained by referring to the simulation results of the respective building types [28], composing the measures overview graph, as the one shown in Figure 2.

The usability of the approach and particularly the energy saving potential overview were validated by building industry professionals, who are expected to use it in the refurbishment strategy decision-making. The information sought was of qualitative nature, as they refer to the design process and the usability of the approach. Therefore, semi-structured interviews were used as a mean of qualitative data collection. The first part of the interview got the respondents acquainted with the approach, while in the second phase, they were asked on their opinion regarding refurbishment design process and the impact of the toolbox information.

The main categories of respondents are designers and stakeholders, divided in different groups. Since the approach focuses on the design phase, architects were an important respondent group to provide feedback. Additionally architectural students working on refurbishment projects were part of the designers' category. Aside from designers, refurbishment decisions are influenced by other building industry parties, referred as stakeholders. The respondents were selected on the basis of their experience on refurbishment decision-making. They include housing companies that are often the refurbishment initiator and shape the specification, together with maintenance and renovation constructors and climate consultant.

The interviews resulted that energy upgrade is typically part of the project requirements. However in most cases it does not influence the concept development and comes as an additional parameter to be incorporated in the final design. Efforts toward reversing this process are taking place, particularly from the stakeholders' point of view. Multi-disciplinary teams, often, but not always, with the participation of architects, aim at making refurbishment decisions based on the solution performance. Stakeholders appear to be more aware compared to architects of the need to integrate the energy performance in their decisions. The reason is the direct relation of energy savings and cost, which is the most decisive factor for stakeholders. Housing companies and refurbishment consultants are already using tools to get early indicators of performance, while architects mostly rely on their experience and general knowledge. In this context, the approach focus on architects is justified. In general, the participants believed that the toolbox information is useful to provide an overview of possibilities and arguments within the design team. Even if the decision is not on the measure with the higher energy savings, it is beneficial that it triggers the discussion on why an efficient measure is not selected. On the other hand, it can direct the design towards high-saving options. Most importantly, the information can be valuable when negotiating possible options with clients.

The investment cost came up several times during the interviews, as the main factor to determine the decisions taken by the client. Even though the approach does not provide specific numbers for the cost of a measure, it addresses its importance as a parameter in the matrix organisation. Measures that are more intervening and are,

hence, expected to be more expensive are placed after the less intervening measures. Calculating the expense of a measure it is not possible within the scope of the approach as it depends on the specific project, in terms of scale, location, detailing of the solution etc. Nevertheless, when a specific project is considered and the expenses are known, the toolbox information can easily give an indicative payback time, based on the calculated energy savings.

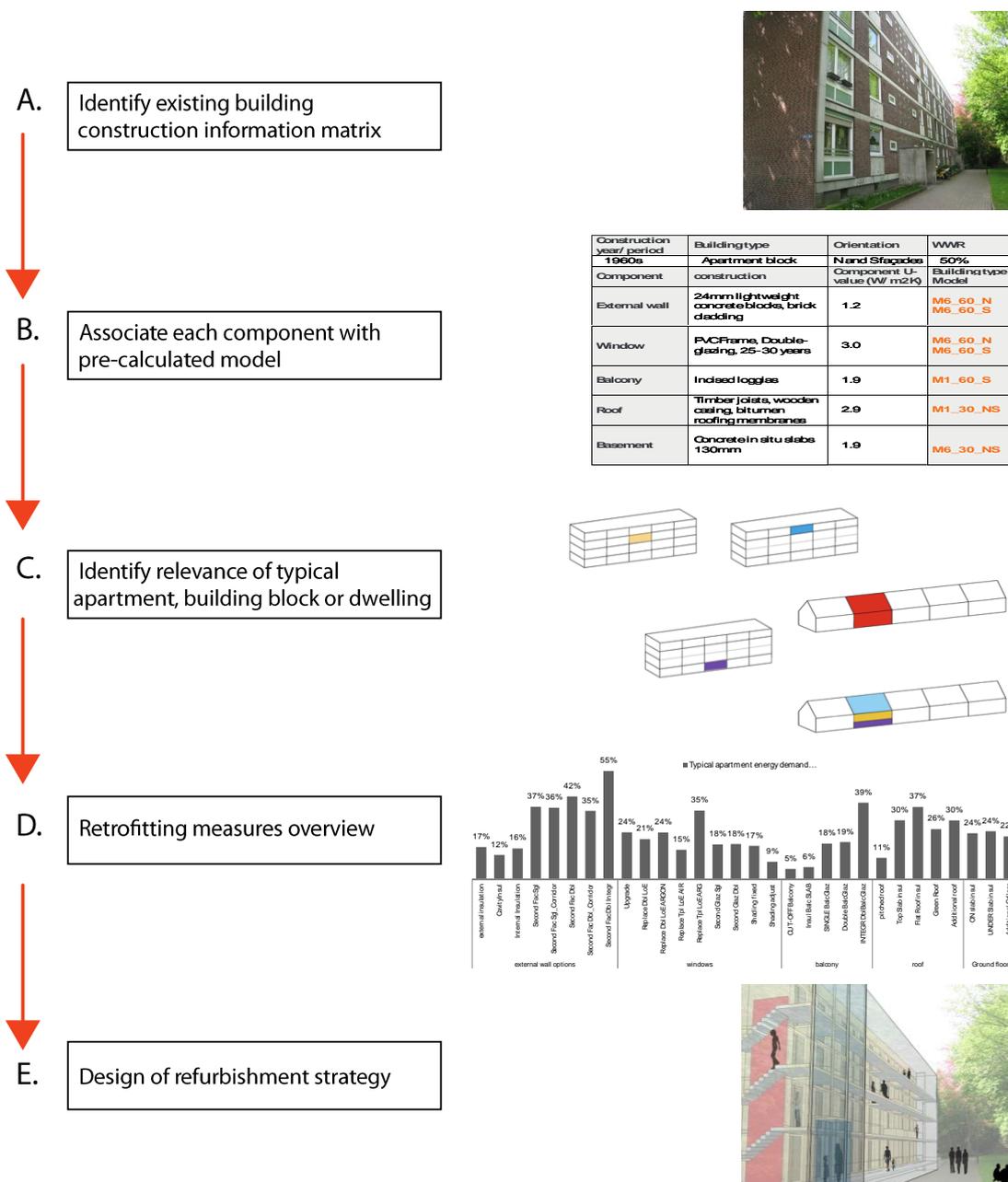


Figure 3: Steps to associate an existing building with the Façade Refurbishment Toolbox (FRT) approach pre-calculated models. In this way, an indication of energy saving potential of different retrofitting measures is available without new simulations.

4 Conclusion

The Façade Refurbishment Toolbox (FRT) approach provides information that can support the decision-making of residential façade refurbishment strategies. Firstly, the building envelope components that need to be addressed in an integrated refurbishment strategy are identified and different retrofitting measures for each one are proposed, composing the façade refurbishment toolbox. Secondly, the measures are quantified in terms of energy upgrade potential, expressed by the simulated energy demand reduction after the measure application.

As a result, the toolbox calculations provide an indication of the potential energy demand reduction at the early stages of the design and give the possibility to compare different measures when decisions need to be taken. Additionally the toolbox matrix helps in organising the available options and highlight key considerations during the process that the toolbox information can have an impact on. All the information can support the decision-making within the refurbishment strategy design team. The approach primarily targets the architect, that has to make the design development, but the information can also be used by users, owners and other stakeholders.

To validate the approached further applicability, building industry experts, designers and stakeholders were interviewed to give feedback on the qualitative assessment of the approach usability. The respondents were selected on the basis of their experience on refurbishment decision-making. Apart from designers, who are the main target of the approach, housing corporation and renovation constructors were included as validating parties.

Both designers and stakeholders have found the energy saving potential and the level of information provided by the approach useful information, not only during their own decision-making, but also in their argumentation within the project team and the client. The approach provided a general, but clear idea for the effect of different measure, by quantifying measure impact on energy demand. If more specific data on energy consumption are needed, simulating the performance of the final strategy is required. Nevertheless, this does not conflict with the objective of the FRT, which aims at providing an indication at the early stages of the design. The integration of measures' cost was recommended as further development of the toolbox. Additional consideration that influence the decisions, particularly from the architects perspective, included the improvement of building's function and appearance, the flexibility of the solution to be adjustable to occupants needs and the preservation of building existing value. The toolbox information can support the decision, integrating the energy savings to the project specifications, leading to the design of energy conscious refurbishment strategies for the residential buildings' façades.

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