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Improved methodology for affordable, reliable deep building renovations

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Abstract. European Union energy efficiency goals put refurbishments in focus as the existing building stock takes a high share in the final energy consumption meanwhile current refurbishment rates are lower than expected. This research attempts to answer the question: How can renovation processes be improved to raise renovation rates? The methodology development process consisted of identifying the methodological background, the phases and steps of the renovation process and the validation strategies. As a result, five methodological phases were identified. Renovations start with the Feasibility phase where a simple financial and technical assessment is carried out. During the Preparation phase necessary information is collected which results in a calibrated simulation model that can support the design. In the Design phase the renovation options are developed and assessed together with a business plan for financing the implementation through renovation cycles. The renovation measures are carried out during the Implementation phase. In the Operation phase the performance of the refurbished building is monitored and improved. The developed methodology is expected to provide more affordable, reliable building renovations, which reduces the performance gap, the upfront investment and the disruption of user life by reducing overall time on site. This results in an increased investment efficiency leading to higher uptake of refurbishments.

1. Introduction

The decarbonization of the European building stock, of which 85-95% will still be standing in 2050 [1], is a necessary step to reach the net zero greenhouse gas emissions target of the European Climate Law by 2050 [2] as it takes a high share in the final energy consumption (40% of energy consumed in the EU). However, the current annual energy renovation rates across the EU are only around 1% with an average primary energy savings of 9% for residential, and 17% for non-residential buildings. Only 0,2% of renovations are considered deep renovations, where at least 60% energy consumption reduction is achieved [3].

The European Green Deal strategy identifies the renovation of the existing building stock as a key initiative to drive energy efficiency in the construction sector, so within that the European Commission is targeting the doubling of the renovation rates by 2030. To pursue this ambition, the Commission published on 14 October 2020 a new strategy to boost renovation called "A Renovation Wave for Europe – Greening our buildings, creating jobs, improving lives". The Renovation Wave strategy aims to renovate thirty-five million inefficient buildings by 2030 to reduce emissions by at least 55% and to build the foundations for a climate neutral Europe by 2050 [1].

A report for the European Commission [3] identifies various causes of the low uptake of refurbishments: skills (expertise is needed to select technical measures and calculate costs and benefits), administrative aspects (complicated administrative requirements), financial (high upfront costs, unwillingness of taking out loans), technical barriers (building properties do not allow energy renovations) and lack of personal benefits (negative effects on comfort and IAQ, split incentives). The strongest obstacles that prevent the implementation of energy renovation are financial barriers.

The goal of this research closely relates to this proposal to accelerate renovations, as it attempts to answer the question: How can renovation processes be improved to raise renovation rates?

Many publications describe decision making tools for stakeholders for construction processes [4], providing a multi-criteria based decision making method to be able to consider environmental, energy, financial and social factors [5]. The common renovation process is also defined in literature. Ma et al. [6] identifies five major phases: 1, project setup and pre-retrofit survey phase to define the scope and target of a project; 2, the energy audit and performance assessment phase analyses the performance of the existing building; 3, the identification of retrofit options phase usually gives a quantitative assessment of the retrofitting alternatives; 4, the site implementation and commissioning phase and the 5, validation and verification phase. Similar phases are described in other literature as well, with some variations [7]. Some research aims to enhance the process by focusing on a sustainability aspect (e.g.: reducing lifecycle environmental impact [8], reducing energy use), a specific building type (e.g.: residential building renovation [9]), developing supporting tools (e.g.: digital twins for reducing performance gap [10]) or integrating technologies (e.g.: industrialized solutions [11]).

The current research builds upon the identified current renovation process and enhances it with the criteria described in the following chapters.

2. Methodology

A three-phase process was developed to establish the renovation methodology: establishing the background, the renovation methodology and the validation phases (Figure 1).

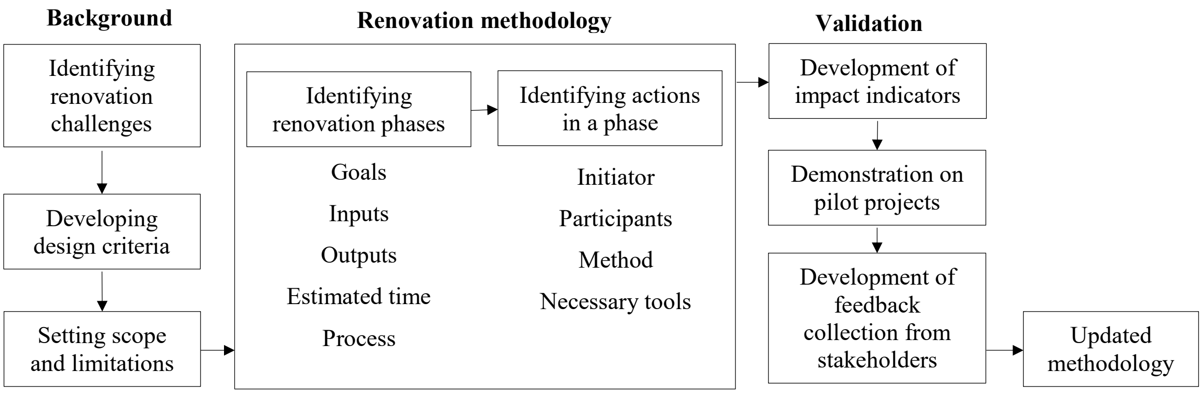

Figure 1: Renovation methodology development process

To develop the background of the renovation methodology, first the main challenges were identified using literature and experience. Then the methodology design criteria were established which define the underlying solutions to enhance the renovation process. Finally, to target the most relevant building stock and owner types, the scope and limitations for implementing this renovation methodology were added, e.g.: focusing on functional types with diverse ownership structures which represent a significant size of the European market: multi owned residential buildings, public non-residential buildings and private office rental buildings; using Key Performance Indicators (KPIs) that mainly cover Energy, Comfort and Cost related topics.

After establishing the background, the renovation methodology was defined. It started with defining the phases for renovation. Each renovation phase is described with the following information: goal of the phase, necessary inputs to start the activities in the phase, the outputs provided at the end of the phase, estimated time to go through the steps of the phase, description of the process. During the description of the process each action includes information about the initiator and participants, the method that can be used to carry out the action and the necessary or recommended tools.

Using these principles an initial refurbishment method was developed to be validated. Impact indicators and preferred target values were defined to measure the compliance with the design criteria. The whole process was tailored to three pilot buildings representing the diverse ownership structures of renovations. The feedback to collected from monitoring equipment and pilot stakeholders was defined and is expected to be used to develop the updated methodology.

The results of the research process development are detailed in the next chapters. However, the validation process of this research is in progress (expected to be implemented in 2022-2023), therefore only the initial methodology is covered in this paper.

3. Results

Figure 2 shows the collected financial (e.g.: high up-front costs, long payback period), technical (e.g.: performance gap between designed and operating buildings) and social (e.g.: disrupting residents' lives, low consideration of all stakeholders) causes of low uptake of refurbishments. These challenges were transformed into measurable objectives, targeting to achieve more attractive and reliable renovations to enhance the understanding and inclusion of renovation needs by potential stakeholders; reduce the performance gap between the designed solution and the operations to enhance the confidence in the design and eliminate unintended negative effects on comfort and IAQ; minimize the time spent on site to reduce the disruption of lives or businesses of building users and eliminate installation mistakes; optimize renovation investments considering the whole lifecycle of the building to reduce capital costs thus accelerating the renovation market.

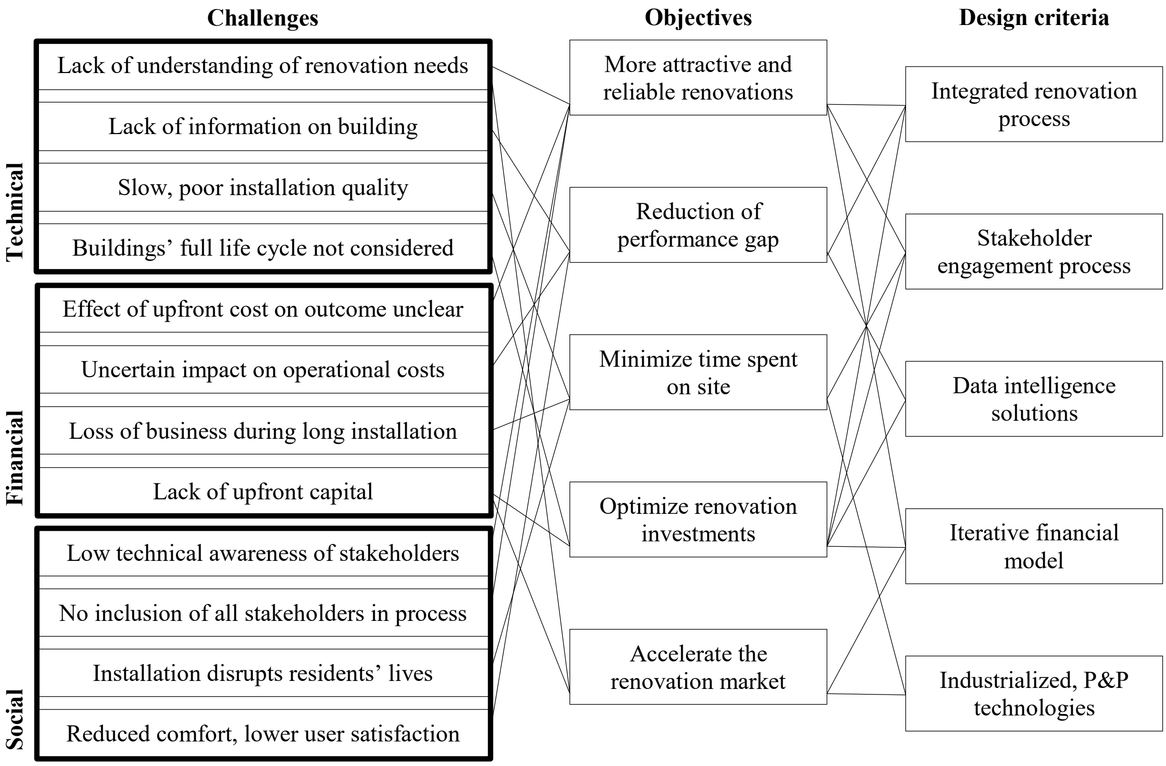

Figure 2: Identified challenges, methodology objectives, developed solutions

Five methodology design criteria are established to deliver the objectives: the inclusion of integrated renovation process, stakeholder engagement process, data intelligence solutions, iterative financial model and industrialized Plug&Play (P&P) technologies.

The integrated renovation process helps deliver more effective, higher quality and less costly construction processes by creating an environment that enhances collaboration, innovation, and value [12]. The renovation methodology development is influenced by these criteria as a Lean delivery method is applied throughout the process to eliminate any activities which do not add value [13].
Pre-assembled, P&P technologies allow deep renovation to be carried out in a drastically reduced time on site [14] thus minimising disruption to the building occupants. The industrialisation of the production also significantly reduces the risk of installation errors, as technologies are integrated off site and can be tested before dispatch to the installation. A plug and play approach in the design and development of products via shared specifications that consider potential integration of disparate technologies based on the requirements of the specific building is also considered. This in turn can enable the clustering of technology providers, generating a third-party market to deliver tailored solution packages and accelerate the market for their products. These criteria affect the methodology development by establishing preference for prefabricated solutions during design assessment, helped by early engagement of product suppliers to deliver tailored solution packages.

The stakeholder engagement process tailored for renovations benefit building owners and operators as it can capture knowledge, increase ownership of buildings by tenants, reduce potential conflicts and encourage innovation. It can also be a forum for the users to participate in decision making and receive new knowledge resulting in increasing awareness, changing attitudes and behaviors towards a more sustainable living. This process is included in the renovation methodology in every renovation phase.

The data intelligence solutions include near-real time data collection identify cost-optimal, high impact interventions at any stage of the building life, rooted in Measurement and Verification (M&V) principles, with robust feedback loops on investor priorities, occupant needs and performance requirements. It can also decisively close the performance gap between design and operating performance. The successful usage of extensive data means the inclusion of careful planning and long-term monitoring plan for a building before and after renovations in the methodology.

A financial model using iterative process to lower upfront investment can present an easier entry to a larger number of investors into the renovation market. The core concept is the implementation of the renovation broken down to several cycles to use the improvement of the building performance and the resulting cost savings from the initially implemented measures towards financing the next cycle.

To support the realization of the methodology several tools are being developed, that can be grouped into two categories: overarching tools, that provide support during all phases of the methodology (e.g.: data intelligence tools, energy simulation tools, stakeholder engagement strategy, Lean project delivery guidelines, P&P protocol) and phase-specific tools, that support actions in specific phases of the methodology (e.g.: feasibility checking tool, simulation model setup and calibration guidelines, P&P technology installation guidelines, M&V guidelines).

3.1. Phases

As a result of the renovation methodology [15] development five renovation phases are identified: Feasibility phase, Preparation phase, Design phase, Implementation phase, Operation phase (Figure 3).

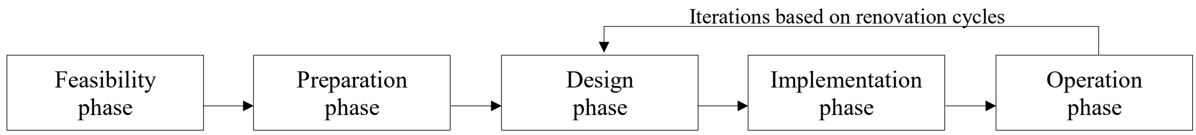

Figure 3: Renovation phases

3.1.1. Feasibility phase

The first phase focuses on the initial action of every renovation project, the decision-making for pursuing a building refurbishment. This decision-making is supported by a financial feasibility study and a technical applicability checklist. Both assessments are based on a simple data collection, where the necessary building related data can be collected during a site walkthrough.

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The feasibility study considers the cost-effectiveness and the co-benefits of pursuing refurbishments. Based on the operating costs and energy use from bills and the investigation of the conditions of energy related systems an initial list of energy conservation measures (ECMs) can be determined with their approximate investment value and potential energy savings or co-benefits. The potential energy savings can be assessed for a package of measures by a simplified simulation model or by hand calculations. Using this data, the feasibility provides a preliminary and basic financial evaluation of the renovation project's expected or required investment in ECMs and the resulting benefits. In addition, it also needs to be decided if prefabricated P&P technologies can be applied to the building by filling out a simple checklist. The applicability is limited by some technical constraints, like the geometry of the façade (to apply modular façade systems) or the type of heat source and distribution system (to determine the applicability of low temperature heating systems). If industrialized ECMs are not applicable for the project, most of this renovation methodology can still be applied, but without benefitting from the advantages of these technologies.

After studying the applicability and feasibility of the renovation, the project initiator can decide on pursuing the renovation.

3.1.2. Preparation phase

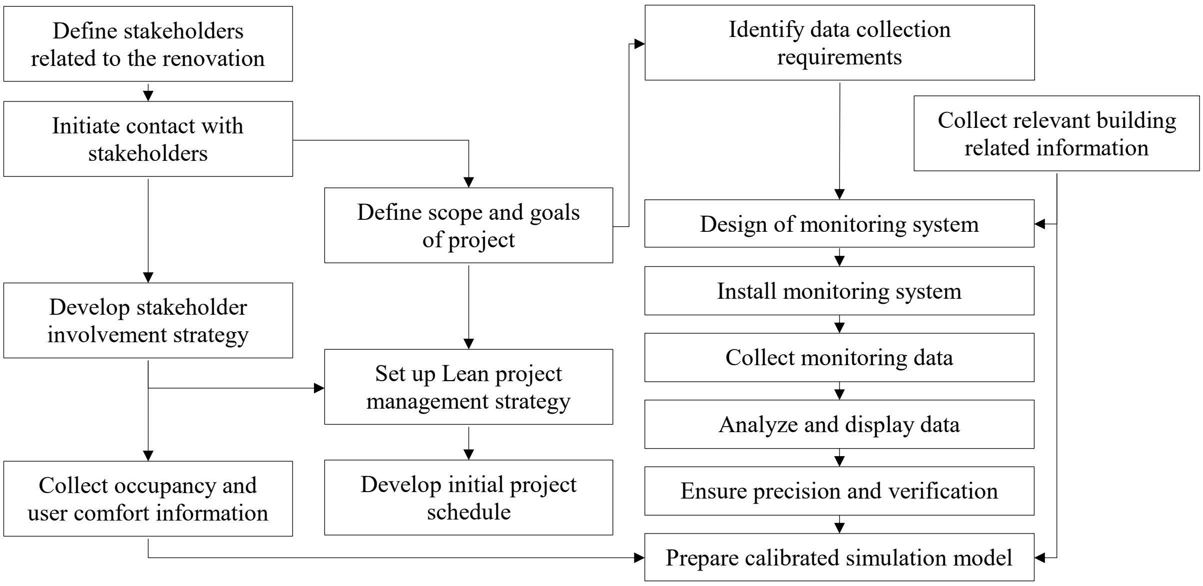

Figure 4: Steps of the Preparation phase

The goal of the Preparation phase is to collect all information, develop the initial scheduling and involve the project stakeholders who are necessary to start the design. This initial scheduling is frequently updated throughout the whole renovation process.

This phase includes the first stakeholder engagement activities, to determine their needs and priorities, which can be used to establish the main goals of a renovation project. The project goals are expressed in the prioritizing of the KPIs. Then the stakeholder involvement strategy that establishes the methods and levels of participation can be customized to the project needs based on the initial interest of the identified stakeholders. The first step of the strategy is to collect user comfort and behavior data through surveys and interviews. Using the identified goals for the project and involving the main stakeholders an initial project schedule can be developed using Lean project delivery process.

Based on the project goals the detailed data collection and monitoring requirements can also be customized, including information on geometric data and all relevant parameters of the building structures. Additionally, supported by data intelligence solutions that collect, analyze, verify and display the incoming information, one year of energy, comfort, user behavior data should be collected.

The data collection results are used to build an energy and comfort simulation model of the existing building and calibrate it to match the real operation patterns and energy use.

3.1.3. Design phase

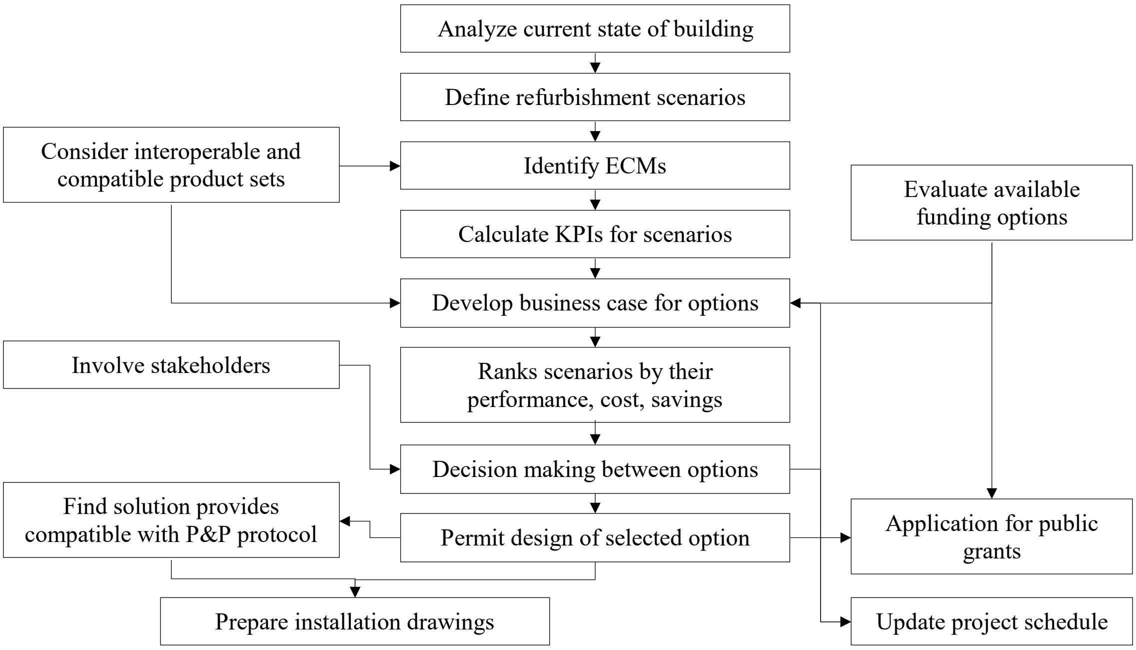

Figure 5: Steps of the Design phase

The main goal of the Design phase is to develop a data driven refurbishment design, starting with the analysis of the current state of the building. The calibrated simulation model can accurately show the low performing structures or systems. To correct the identified inefficiencies different refurbishment scenarios can be proposed. Each scenario is the assessed with the KPIs and for the most suitable options the business case can be developed. This aims to support the project owners in assessing whether an investment in the selected refurbishment scenario makes sense from a financial performance perspective. It also proposes the optimal number of iterations through the selected ECMs can be implemented based on the available investment capital and cost savings that can be reused for further installations.

Considering the energy, comfort and cost savings and other non-energy related benefits of the analyzed renovation scenarios the project stakeholders can select the scenarios most beneficial for their needs. Ideally, the final option will be chosen through a consensus-based approach. The final renovation option needs to be developed into a permit design. This will be further detailed into installation drawings with the support of solution providers who can fit in with the P&P protocols.

3.1.4. Implementation phase

The Implementation phase starts with the procurement process and continues with the installation of the selected solutions. The implementation follows the established project schedule and the Lean project delivery methods. Occupant satisfaction should be also monitored, and the reduced installation times (due to using prefabricated, integrated technologies) should be adjusted to their needs. After the technologies are installed, the energy, comfort and user behavior monitoring system also may need adjustment to include the metering of newly implemented technologies (e.g.: switching from gas boilers to heat pumps with PVs needs new metering equipment).

At the end of the implementation phase the project is handed over to the owner and facility management after a commissioning process supported by the monitoring data to make sure the implemented measures are operating as expected at design phase.

3.1.5. Operation phase

The operation phase consists of several continuous or regular activities to keep track of the condition, energy use, operating costs and user satisfaction. The measurement and verification activities evaluate how the overall performance compares to the targets with using visualized monitoring data and optimize the operations when needed. The ongoing maintenance can be planned and performed efficiently by also tracking the required schedule for equipment inspection and change.

The end of the operation phase includes the preparation for next iteration with updating and recalibrating the simulation model. The business case can also be adjusted with output from revised calibrated model.

4. Discussion, conclusions and further research

To answer to the need of renovating the European building stock this research focuses on developing a new holistic renovation methodology that considers full life cycle of building and input from the whole value chain and is flexible to adapt to a variety of cases. The methodology relies on the selected criteria that influenced what actions should be achieved during each renovation phase. This resulted in a new methodology diverging from the currently used normal process, as it is integrating multiple forward thinking design criteria that covers technological, financial, social aspects while delivering deep renovation targets. This means that the number of renovation phases (as the the concept of cyclical renovation is introduced) and their duration (as they are highly depending on the expected monitoring times) became different while it is possible to implement more complex solutions (with the use of P&P technologies). To successfully implement the developed methodology a long-term commitment to the renovation process is necessary.

This improved methodology attempts to fit into the new EU legislative framework of the Renovation Wave by providing reliable design solutions utilizing extensive information on actual energy consumption and by implementing a staged renovation process.

However, the methodology poses new challenges to stakeholders: owners need to have open mindset towards new technologies, designers and installers need specialized expertise and users and facility managers should adjust to optimized operations. Carrying out a renovation with this methodology also requires a careful scheduling as proper data collection needs sufficient time before any works can be started and the cyclical renovation plan needs willingness to carry out long-term plans. Moreover, there are some technical limitations on its applicability as industrialized technologies can be applied to buildings with certain façade and HVAC system characteristics (e.g.: buildings with simple facades, with sufficient load bearing capacity).

In summary, with the implementation of the developed methodology and with the usage of mainly P&P solutions renovations are expected to achieve the following objectives, which are based on preliminary calculations on example buildings supported by data from real case studies and technology providers working on prototype P&P solutions:

- Reduction of performance gap to 5-10% by developing an integrated lifecycle software solution to plan renovation steps, identify appropriate solutions to reduce energy consumption, improve IEQ, integrate renewable production and storage and optimise operations through continuous refinement and constant verification of targets and constraints.
- Minimise time spent on site by at least 20% with installing P&P solutions (e.g.: modular façade insulation panels, integrated heat source and storage system)
- Optimise renovation investment by reducing upfront investment up to 50% by optimising investment iterations to more renovation cycles
- This results in an increased investment efficiency leading to higher uptake of refurbishments.

To demonstrate the developed approach, the project will implement the methodology on three pilot buildings from different climates representing the three targeted functional types. The pilot works will include two P&P technologies: a prefabricated façade insulation module that can integrate renewables, window, shading, and ventilation products and a heating system integrating PVs, heat pumps and heat storage. The validation of the targets will be achieved through a mix of quantitative and qualitative assessments. The renovation process on the pilot will be monitored and financial and scheduling data is being collected to determine the achieved energy and cost savings and the reduction of time spent with installation. The stakeholders of the pilot renovations will also provide feedback on the applicability of the methodology and the supporting tools. The building users will be able to reflect upon the changes in their comfort levels through surveys and their attitude and behavior changes that affect energy savings will be assessed. Potential investors and technology providers are included in discussions on the potential market uptake of the developed approach.

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