

Standardising Deep-Renovation Planning: An Archetype-Based Methodology for Generating Building Renovation Passports

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Abstract. Building on the requirements introduced by the Energy Performance of Buildings Directive (EPBD), which identifies the Building Renovation Passport (BRP) as a key instrument for supporting long-term renovation strategies, this study proposes a methodological framework for BRP generation, addressing a current gap in the literature. The paper starts with a literature review highlighting limitations in existing BRP approaches, including fragmented data structures, heterogeneous modelling practices and limited scalability across building types and contexts. Grounded on this literature, the paper illustrates an archetype-based modelling methodological framework, whereby reference buildings synthesise the geometric, constructive and operational characteristics of the building stock and provide a reproducible and scalable foundation for BRPs development. This structure enables evaluations across building groups and is combined with a multi-objective optimisation procedure that explores combinations of renovation measures. By producing transparent and quantifiable renovation pathways, the methodology also strengthens the bankability of renovation projects, supporting investment planning and risk assessment. Overall, the integrated approach enables the construction of staged and cost-effective renovation roadmaps aligned with EPBD principles and applicable from individual buildings to city and region scale assessments. The study delivers a unified and operational workflow that addresses key methodological gaps and enhances the technical basis for the practical implementation of BRPs.

1 Introduction

The decarbonisation of the building sector represents one of the central challenges of European climate and energy policy, given its significant contribution to final energy consumption and greenhouse gas emissions [1]. Coherently with this scenario, the European Union has progressively strengthened its regulatory framework, culminating in the recent revision of the Energy Performance of Buildings Directive (EPBD IV) [1] which places renovation at the core of long-term climate neutrality strategies. Within this context, the Building Renovation Passport (BRP) has been identified as a key enabling instrument to

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support planned, staged and cost-effective renovation processes over the building lifecycle [2].

Formally defined by the EPBD IV as a document providing a tailored roadmap for staged renovation, the BRP is based on a comprehensive assessment of a building's current condition and its future improvement potential [1]. While earlier versions of the EPBD primarily focused on Energy Performance Certificates (EPCs) as informational tools, EPBD IV explicitly promotes long-term renovation strategies and the coordination of interventions over time [1]. In this perspective, the BRP is not merely an extension of existing certification schemes, but a distinct instrument with specific methodological implications [3]. By structuring renovation decisions over time, BRPs are expected to overcome the limitations of single-step interventions and to facilitate the achievement of deep renovation targets. Moreover, by improving transparency and predictability, BRPs are increasingly recognised as instruments capable of supporting investment planning and enhancing the bankability of renovation projects [4]. In particular, the standardisation of renovation stages allows financial institutions to better assess the risk-return profile of long-term investments, bridging the current gap between technical potential and financial feasibility [5]. To synthesise the extensive list of requirements set by the EPBD, the BRP can be conceptually divided into five interrelated information domains (macro-categories): **Current Building Status**, outlining the baseline technical and energy characteristics of the building (EPBD Annex VIII, point a); **Renovation Roadmap**, describing the sequencing and representation of the renovation pathway (points b, d, e); **Technical Solutions and Performance Outcomes**, detailing the qualitative and quantitative aspects of renovation measures and expected results (points e, f, g, h); **Regulatory Context**, covering national and European regulatory requirements and targets (point c); and **Financial Advisory Support**, addressing funding mechanisms and advisory services supporting implementation (points i, j).

Translating these policy objectives into operational methodologies poses several challenges. First, BRPs require integrating heterogeneous data sources, including geometric information, construction characteristics, system configurations, and usage patterns [6]. Second, they must support decision-making over extended time horizons, accounting for interactions between renovation measures and evolving performance targets [7]. Third, they need to be sufficiently standardised to enable comparability and aggregation [2], while remaining flexible enough to accommodate different building typologies and national contexts [8]. From a methodological standpoint, these requirements suggest that BRPs cannot be effectively generated through purely building-specific or ad hoc approaches. Instead, they call for structured modelling strategies that reduce complexity while preserving representativeness. In this sense, archetype-based modelling [9] emerges as a promising foundation, as it allows the synthesis of key characteristics of the building stock into reference entities that can be systematically analysed and compared. When combined with optimisation techniques, such representations can support the exploration of multiple renovation pathways and the identification of robust solutions under competing objectives. Furthermore, the growing emphasis on the financial dimension of renovation underscores the need for BRPs to deliver transparent, quantifiable outputs. Beyond energy and emissions indicators, renovation roadmaps must provide cost-related information that is readily interpretable by building owners, financial institutions and public authorities. This reinforces the importance of methodological coherence, as inconsistent modelling assumptions and fragmented data structures undermine the credibility and usability of BRPs as decision-support tools. From a scientific perspective, this fragmentation reflects the lack of a unified, scalable methodological foundation for BRP generation. Current contributions, such as the Italian iBRoad2EPC roads and ALDREN BRP for non-residential buildings, the Flemish Woningpas or the German 'individueller Sanierungsfahrplan' (iSFP), demonstrate the practical viability of BRPs through application-driven tools and local pilot studies, focus on

application-driven tools or local pilot studies, while limiting on the definition of reproducible workflows capable of bridging policy requirements, technical modelling and decision-support needs [10].

Against this background, this paper addresses the need for a coherent methodological framework for generating BRPs. Rather than proposing a new application or validating a specific case study, the study focuses on defining an operational and scalable workflow, grounded in archetype-based building representation [11] and multi-objective optimisation principles. By building upon a critical assessment of the existing literature and policy requirements, the proposed methodological framework aims to provide a robust technical basis for the practical implementation of BRPs, applicable across different building types and spatial scales.

2 Literature review

2.1 Systematic literature review methodology

This systematic literature review was conducted following the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines to ensure transparency, reproducibility and methodological framework in the identification and selection of relevant studies. The review aimed to explore the evolution of research on the Building Renovation Passport and related policy and digital instruments within the European Union framework, with a focus on the EPBD. The review was performed using the Scopus database, which provides broad multidisciplinary coverage and consistent indexing of peer-reviewed publications. The query was designed to capture research at the intersection of building renovation, energy efficiency and digital or policy instruments, including terms such as “building renovation passport”, “digital building logbook”, “energy performance certificate” and “EPBD”. The search was limited to journal articles and conference papers published between 2018 and 2025, corresponding to the main stages of evolution of the EPBD framework (2018 amendment and 2024 recast). A total of 89 records were initially identified through the Scopus search and the selection process that involved filtering stages is illustrated in the PRISMA 2020 flow diagram of Figure 1. During the identification phase, 6 records were removed prior to screening since they were not written in English. A total of 83 records were screened based on title and abstract, resulting in the exclusion of 18 papers that did not meet the relevance criteria regarding the BRP concept or related methodological frameworks. Consequently, 65 reports were assessed for full-text eligibility. In addition to the Scopus database, three complementary reports were identified through other sources, namely: the Buildings Performance Institute Europe (BPIE), the EPBD-wise databases repository and the Institute for Energy and Environmental Research (ifeu). No further exclusions were necessary at this stage. As a result, 65 studies and 3 technical reports were included in the final literature review.

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources

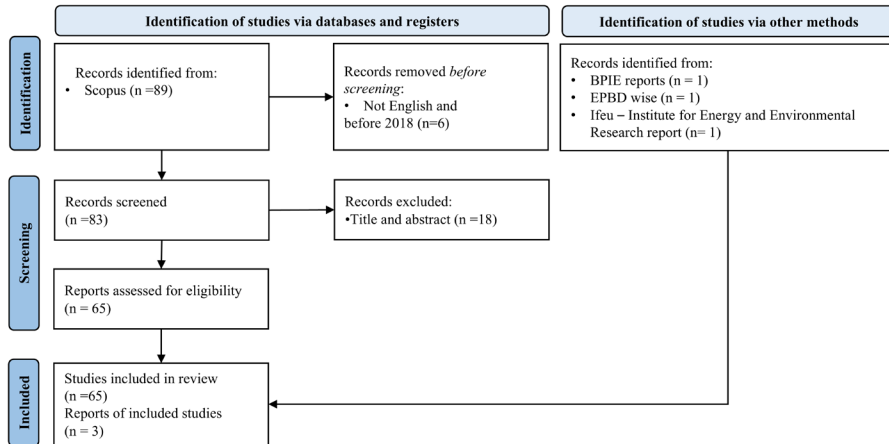


Fig. 1. PRISMA flow diagram illustrating the identification, screening, eligibility, and inclusion process of studies considered in the literature review on Building Renovation Passports (BRPs).

2.2 Bibliometric overview and research trends

A bibliometric analysis was conducted to identify co-occurrence relationships among keywords. The resulting network reveals four main clusters of keywords.

- **Policy and renovation frameworks cluster.** Centred around building renovation, energy efficiency and investments, this cluster highlights research focusing on policy instruments, financial mechanisms and decision-making processes supporting building renovation strategies. It reflects the socio-economic and governance dimension of BRPs.
- **Digitalisation and performance assessment cluster.** Keywords such as digital building logbook, energy performance certificate and energy performance form a coherent group that deals with data integration and digital tools. This domain reflects the technological backbone of BRP implementation, emphasizing interoperability and data-driven renovation tracking.
- **Decarbonisation and retrofitting strategies cluster.** The terms decarbonisation, retrofitting and building stocks define a research area addressing large-scale energy transition goals and building stock transformation. It focuses on strategies for achieving deep renovation and carbon neutrality at systemic scale.
- **Sustainability passport.** Including building passport, sustainable development and digitalisation, this cluster links the BRP concept to overarching sustainability and digital transformation agendas, indicating the cross- disciplinary connections of BRPs.

In terms of temporal evolution of the publications, the literature review reveals that the number of studies on BRPs has grown steadily since 2018, with a marked increase after 2023 and a peak in 2024. This trend clearly reflects the growing policy relevance of the topic, following the European Commission's Renovation Wave Strategy (2020) (European Commission, 2020) and the legislative process leading to the 2024 EPBD recast. In addition, there is a post-2023 peak that suggests that the BRP has become a central research focus within the broader transition renovation frameworks.

Finally, in terms of geographical distribution of studies across the European Union; the highest concentration of contributions is observed in Portugal, Spain and Italy, reflecting the proactive engagement of Southern European research groups in developing and testing BRP methodologies. Significant research activity is also visible in Denmark, Austria and Germany. In contrast, limited representation from Eastern and Northern Europe suggests uneven research coverage, potentially linked to differences in national renovation policies and data availability.

2.3 Results and discussion

The following section presents a synthesis of the literature review, which involved a comprehensive screening of recent academic contributions and policy reports. Due to spatial constraints, this discussion focuses on the most significant findings that directly inform the proposed methodological framework.

A systematic mapping of contributions reveals that the scientific literature on BRP has expanded in parallel with policy developments and pilot initiatives across Europe [8,13]. Existing contributions encompass a wide range of approaches, from simplified advisory tools to detailed simulation-based analysis [10,14]. Many studies focus on the development of BRP prototypes tailored to specific national contexts, often building upon existing EPC schemes or energy audit procedures [15]. While these approaches demonstrate the potential of BRPs to support renovation planning, they also reveal significant heterogeneity in terms of objectives, methodological assumptions and output formats [16]. Several studies adopt a checklist-based or rule-based logic, providing predefined renovation recommendations without explicitly modelling interactions between measures or long-term pathways [10]. Others rely on detailed building simulations, which, although technically robust, tend to be resource-intensive and difficult to scale beyond individual case studies [13]. A common limitation across the literature is the strong dependence on building-specific data and modelling choices [17]. As a result, BRPs are frequently developed as bespoke products, limiting their transferability and comparability [18]. This fragmentation complicates the alignment of BRPs with broader renovation strategies and hampers their integration into large-scale policy frameworks [19].

This diversity in strategic approach is deeply rooted in, and further complicated by, the fragmented nature of data structures and modelling practices currently in use [20,21]. Existing BRP methodologies draw on diverse data models, including EPC databases, building audits, BIM-based representations, and statistical building stock models [10,17,22]. However, these data sources are rarely integrated within a coherent framework, leading to fragmented information flows and inconsistent assumptions [20]. Modelling practices also vary widely, ranging from steady-state calculations to dynamic simulations and hybrid approaches [10,13,16]. While each method has specific advantages, the lack of standardisation undermines the reproducibility of results and limits the transparency of renovation pathways [21,23,24]. In particular, the absence of harmonised building representations makes it difficult to compare BRPs across different contexts or to aggregate results at district, city, or regional scale [18,24]. These issues are further compounded by the need to balance model complexity and usability. Highly detailed models may offer precise results but are often incompatible with the large-scale deployment envisaged by EPBD IV as they may require excessive human resources and specialized IT support [18,23]. Conversely, overly simplified approaches risk oversimplifying renovation dynamics and overlooking critical interactions between measures [25].

Ultimately, the inability to aggregate building-level data into broader policy insights highlights a clear disconnect between the high-level ambitions of the EPBD IV and the practical, bankable tools available to stakeholders [4]. While many studies successfully

demonstrate the feasibility of BRPs at the individual building level, few address the methodological requirements for extending these approaches to building groups or entire building stocks [8]. This limitation is particularly relevant in the context of national renovation strategies, where policymakers require aggregated insights to prioritise interventions and allocate resources effectively [8,19]. Moreover, the decision-support dimension of BRPs remains underdeveloped. Although energy and emission indicators are commonly reported, economic aspects are often treated in a simplified or inconsistent manner [8,13,16]. This limits BRPs' ability to support investment decisions and weakens their potential to improve the bankability of renovation projects. Overall, the literature highlights a clear gap between the policy ambitions associated with Building Renovation Passports and the methodological tools currently available to support their implementation [4]. The absence of unified, scalable, and transparent workflows underscores the need for a new generation of BRP methodologies capable of bridging building-level analysis and large-scale renovation planning.

As a synthesis of the literature review, Table I reframes Building Renovation Passports (BRPs) as a set of interconnected domains, as defined in Annex VIII of the EPBD, and highlights the main methodological limitations identified in the literature for each domain.

Table 1. Key domains of Building Renovation Passports (BRPs) according to EPBD Annex VIII and associated methodological limitations identified in the literature.

Macro-category	Actual limitations
Current Building Status	<ul style="list-style-type: none"> • Heterogeneous data sources • Low interoperability • Limited standardisation
Renovation Roadmap	<ul style="list-style-type: none"> • Static or rule-based pathways • Low comparability
Technical Solutions and Performance Outcome	<ul style="list-style-type: none"> • High modelling variability • Low scalability • Limited reproducibility
Regulatory Context	<ul style="list-style-type: none"> • Weak policy alignment
Financial and Advisory Support	<ul style="list-style-type: none"> • Simplified economic assessment • Limited bankability • Weak decision support

3 Methodological framework proposal

The proposed methodological framework develops a structured, reproducible workflow for generating BRPs in compliance with the staged deep renovation principles introduced by EPBD IV. The core of the methodology lies in transitioning from isolated building-specific assessments to an archetype-based framework that streamlines the generation of renovation roadmaps by leveraging standardized models to achieve both scalability and robustness. As illustrated in Figure 2, the methodology is organised into four integrated stages, moving from stock characterisation to the automated delivery of renovation roadmaps.

The process begins with **Step 1, Standardisation and Scalability**, which focuses on the creation of a comprehensive database of reference building archetypes (Step 1.1). This stage integrates open-source databases, such as CEER/CENED (Certificazione ENergetica degli EDifici) and CURIT (Catasto impianti termici Lombardia) with granular data from established research projects like URBEM (Urban Reference Buildings for Energy

Modelling). Rather than relying on simple statistical averages, each archetype is developed as a representative model capturing specific geometric, constructive, and operational thermophysical properties. A critical component of this phase is the calibration and validation process (Step 1.2), where models are refined against measured energy consumption data to ensure reliability when this data is available. These calibrated archetypes then undergo dynamic energy simulations to establish a baseline (Step 1.3) for energy performance, carbon emissions, and indoor comfort.

Once the baseline is secured, the methodological framework proceeds to **Step 2, Renovation Actions**, where a modular matrix of potential interventions is defined (Step 2.1). Renovation measures are grouped into three main categories: envelope renovation, system renovation and integration with renewable energy technologies. By combining these measures into diverse renovation packages, the methodology explores multiple decarbonisation trajectories. Each combination is processed through dynamic energy simulations (Step 2.2) to quantify their effects on energy performance, emissions reduction and comfort improvement, creating a dataset that serves as the foundation for the subsequent analytical phase.

To handle the complexity of these combinations **Step 3, Optimization** employs a multi-objective optimization approach. Central to this stage is the definition of a robust set of Key Performance Indicators (KPIs) for cross-comparison (Step 3.1). The optimisation engine evaluates potential pathways, considering budget constraints, regulatory thresholds, and technical feasibility (Step 3.2). Unlike traditional static assessments, this step identifies "Pareto-front" solutions (Step 3.3), optimal trade-offs between conflicting objectives such as lifecycle costs, operational CO₂ emissions, and energy savings, thereby preventing "lock-in" effects and ensuring that short-term actions do not jeopardise long-term decarbonisation goals.

The final **Step 4, Roadmapping**, automates the translation of these optimised solutions into actionable BRPs through a reproducible computational workflow (Step 4.1). This unified pipeline bridges the gap between technical data and user-centric outputs (Step 4.2). The proposed methodological framework delivers two complementary results: a detailed technical roadmap that standardises renovation proposals for homeowners and auditors, and a strategic assessment tool designed for policymakers. By providing a scalable procedure to evaluate long-term impacts, the methodology ensures that building-level implementation is directly linked to regional and national climate targets, effectively resolving the standardisation and scalability bottlenecks identified in the literature.

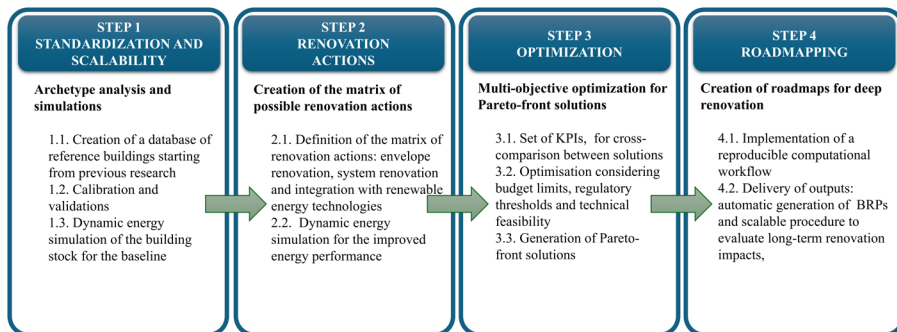


Fig. 2. Step of the methodology: Standardization and scalability, renovation actions, optimization and road mapping.

4 Methodological innovation and comparison with current practice

The transition towards a decarbonised building stock relies heavily on the role the different market operators in the building renovation field. In this paper, the case study relies on the Energy Service Companies (ESCOs) that, according to the European Directive 2012/27/EU, provide energy services with performance-based contracts, effectively shifting the technical and financial risks away from the end-user. Within the Italian context, A2A Energy Solutions (AES) represents a key market operator implementing such models. This research takes AES's current practice as a baseline to identify the structural bottlenecks in the renovation workflow and proposes an archetype-based methodology to overcome them.

In current renovation practice, the workflow typically follows a sequential and building-specific approach. The process starts with an individual building, based on which a preliminary agreement with the client is established at a very early stage. This agreement is generally grounded on high-level estimates that do not fully disclose the underlying technical and decision-making process to the client. Only subsequently, a technician performs an energy diagnosis of the existing conditions, and a building-specific renovation project is developed. Only after the technical solution has been defined is the associated business model formulated, eventually leading to the final contractual negotiation.

As illustrated in Figure 3, this approach is inherently centred on single case studies and requires the full repetition of the technical, economic and contractual workflow for each individual building. While this ensures detailed, customised solutions, it is also highly time-consuming and costly, particularly in the early stages of project development. Moreover, reliance on building-specific assessments limits the scalability of renovation initiatives and constrains market operators' ability to engage proactively with multiple clients.

From a systemic perspective, this structure also hinders early-stage involvement of financial actors. Since technical solutions and business models are developed only after detailed building-level assessments, banks and investors typically have access to limited and non-comparable information during the initial phases. This fragmentation reduces transparency, increases perceived risk and ultimately affects the bankability of renovation projects.

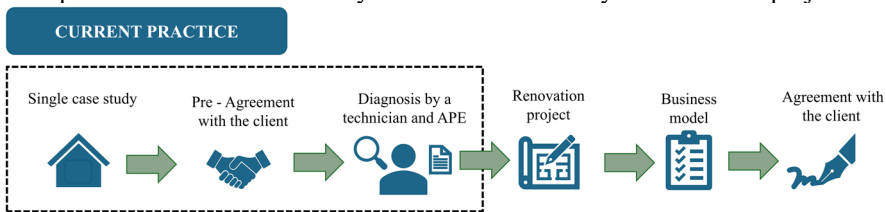


Fig. 3. Current renovation workflow: a linear, building-specific approach characterized by high transaction costs and fragmented project development.

The methodological framework proposed in this study introduces a structural reorganisation of the early stages of the renovation process. As shown in Figure 4, instead of starting from individual buildings, the workflow is based on a dataset of representative building archetypes, each associated with a predefined set of renovation scenarios analysed through dynamic energy simulation. This archetype-based approach enables *ex ante* renovation assessments across groups of similar buildings, providing a scalable, reproducible foundation for generating BRPs. The resulting BRPs are aligned with the EPBD requirements and incorporate Pareto-optimal renovation pathways derived from multi-objective optimisation. Crucially, in this methodological framework, the BRP is not conceived as a static document produced at the end of the design process, but as an intermediate decision-support tool. By integrating technical performance, cost and emissions indicators in a transparent and

standardised format, BRPs can directly inform the preliminary definition of renovation strategies and associated business models. This reorganisation does not replace building-specific design or contractual negotiation. Rather, it reduces the analytical burden and uncertainty in the early stages by shifting a significant share of the assessment effort upstream, before engagement with individual clients.

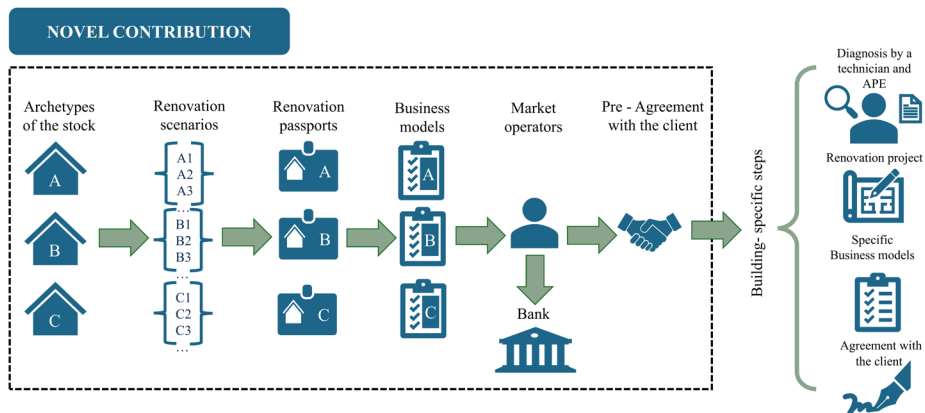


Fig. 4. Novel contribution with the proposed archetype-based methodology: shifting the analytical effort upstream to enable automated BRP generation and scalable renovation road mapping.

4.1 Implication for scalability and bankability of renovation projects

The proposed methodological innovation has direct implications for both market operators and financial stakeholders. By relying on archetype-based datasets and pre-simulated renovation scenarios, market operators can approach multiple clients with robust preliminary information, avoiding the need to initiate each project from scratch. This enhances the scalability of renovation initiatives and supports the partial standardisation of early-stage renovation proposals.

From a financial perspective, the availability of transparent, comparable datasets enables banks and investors to assess renovation options using consistent KPI. This facilitates risk assessment and investment planning, as renovation pathways can be evaluated in terms of expected performance, costs and emissions reductions before building-specific refinements are undertaken.

Overall, the methodological innovation lies not in the introduction of new technical tools, but in the integration and reorganisation of existing modelling, simulation and optimisation methods into a unified and operational workflow. By aligning technical assessment, policy requirements and financial evaluation within a single methodological framework, the proposed approach addresses key limitations of current renovation practice and strengthens the technical basis for the practical implementation of Building Renovation Passports at scale.

5 Conclusions

This study proposes an operational methodological framework for generating BRPs aligned with the requirements of EPBD IV. By addressing key limitations identified in existing BRP approaches, namely fragmented data structures, heterogeneous modelling practices and limited scalability, the proposed methodological framework contributes to strengthening the technical basis for large-scale renovation planning.

The core contribution of the research lies in the integration of archetype-based modelling, dynamic energy simulation and multi-objective optimisation within a single, reproducible workflow. By shifting analytical effort to the early stages of the renovation process and structuring renovation assessments around representative building archetypes, the methodology enables the systematic generation of staged, cost-effective renovation roadmaps applicable across different building types and spatial scales.

Beyond its technical dimension, the methodological framework supports improved interaction between technical, market and financial actors. The generation of transparent, comparable renovation pathways enhances the bankability of renovation projects by enabling preliminary investment assessments based on consistent performance indicators. In this sense, Building Renovation Passports are reframed as intermediate decision-support tools that facilitate early-stage engagement and reduce uncertainty in renovation planning.

The study is intentionally focused on methodological development and does not include an empirical case study. Future research will apply the proposed methodological framework to real-world building stocks at city and regional scales, with the aim of validating its practical implementation, refining archetype definitions and assessing the robustness of optimisation outcomes.

Overall, the proposed approach supports a scalable and policy-aligned implementation of Building Renovation Passports, contributing to the operationalisation of EPBD objectives and to the acceleration of deep renovation strategies in the European building stock.

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