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RESEARCH ARTICLE

REVISED The multifaceted POSIFIT approach to tackling barriers to energy-positive homes

Previously titled: "The multifaceted LEGOFIT approach to tackling barriers to energy-positive homes"

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v2 **First published:** 14 Apr 2025, **5**:103.1
https://doi.org/10.12688/openreseurope.18986.1

Latest published: 6 Nov 2026, **5**:103.2
https://doi.org/10.68336/kpp73h16

Abstract

Background
The European building stock is mostly outdated and energy-inefficient. Still, the transition towards energy-positive homes (EPHs) is hampered by the fragmentation of the renovation/construction processes and the lack of awareness about EPHs' long-term benefits and co-benefits which are not currently monetised. This paper presents the findings of the POSIFIT Project, which aims to develop and validate an integrated approach to EPHs in five pilot countries. POSIFIT provides professionals and end-users with an innovative holistic design platform with three main functionalities: 1) supporting the decision-making process; 2) aiding the design process; and 3) setting up an innovative marketplace to improve communication/experience exchange among stakeholders.
Methodology To achieve the final goal of EPHs, it is essential to focus on four main pillars, each playing a key role in identifying the barriers and drivers in the implementation of EPHs. POSIFIT's approach is built on four pillars: defining EPHs with an emphasis on bioclimatic performance; establishing a comprehensive renovation/construction framework; testing the approach in diverse contexts; and fostering a stakeholder community. A four-step methodology guides the project: framework setup, data collection, data analysis, and validation.
Results and Discussion Analysis reveals that barriers to EPH adoption are prevalent across pilot countries and are amplified in EPH projects. These barriers primarily affect stakeholders undertaking interventions. The POSIFIT platform offers solutions to potentially tackle these challenges. Drivers for EPH adoption can be leveraged by service providers and homeowners. POSIFIT contributes to exploiting these drivers through a systematic approach to energy/financial analysis, raising awareness, and promoting circular resource use.
Conclusion POSIFIT offers an innovative understanding of EPHs,

Open Peer Review

Approval Status ? ?

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version 1 14 Apr 2025	? view	? view

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Any reports and responses or comments on the article can be found at the end of the article.

redefines renovation/construction processes, and provides a comprehensive view of the EPH ecosystem. By identifying stakeholders affected by barriers and drivers, POSIFIT offers targeted solutions for EPH implementation across different project phases and contexts.

Keywords
Energy-Positive Homes, building renovation; new construction, barriers, drivers, dynamic integrative approach, LEGOFIT Platform

This article is included in the Horizon Europe gateway.

This article is included in the Sustainable Places 2024 collection.

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Author roles: De Aloysio G: Conceptualization, Data Curation, Investigation, Methodology, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Laghi L**: Project Administration, Validation; **Savorani P**: Investigation, Methodology; **Alpagut B**: Conceptualization, Data Curation, Funding Acquisition, Methodology, Project Administration, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Miguel Mitre E**: Conceptualization, Data Curation, Methodology, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Mermertaş M**: Funding Acquisition, Validation, Writing – Review & Editing; **Tabanoğlu O**: Funding Acquisition, Validation; **Özcan Z**: Conceptualization, Data Curation, Funding Acquisition, Investigation, Methodology, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No [101104058] (Adaptable technological solutions based on early design actions for the construction and renovation of Energy Positive Homes [LEGOFIT]).
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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How to cite this article: De Aloysio G, Laghi L, Savorani P *et al.* **The multifaceted POSIFIT approach to tackling barriers to energy-positive homes** Open Research Europe , **5**:103.2 https://doi.org/10.68336/kpp73h16

First published: 14 Apr 2025, **5**:103.1 https://doi.org/10.12688/openreseurope.18986.1

REVISED **Amendments from Version 1**

The following summary outlines the key revisions incorporated into the manuscript in response to the reviewer comments:

Project Name Update: We would like to draw your attention to an important update: following some project-related difficulties, the project has officially changed its name to POSIFIT. This updated name also appears on the project website, as shown in the attached screenshot. Consequently, the manuscript has been globally updated to replace the "POSIFIT" acronym with "POSIFIT"

Literature and Citations: An official European Commission citation was added to the Introduction to substantiate the statement regarding the outdated European building stock. Additionally, the bioclimatic performance section (Pillar A) was expanded to include relevant literature on Passive House standards, specifically referencing studies by Schnieders et al., Sadineni et al., and Pacheco et al.

Methodological Diagram: As requested by the reviewers, a new schematic diagram (Figure 1) was added to visually summarize the four theoretical and methodological pillars on which the project's work is based.

Workshop Methodology: The methodology section was updated to provide specific details on the stakeholder workshops, noting that they were two-day collaborative mapping sessions conducted via the online platform.

Qualitative Analysis and Validation: To ensure full methodological transparency, new "Data analysis" and "Validation and refinement" subsections were incorporated. These sections explicitly detail how the qualitative data from the workshops was categorized, prioritized, and subsequently validated by the project partners.

Figures and Outputs: The figures illustrating the identified barriers and drivers (now Figures 9 and 10) have been updated. They now include captions indicating they were prepared in response to feedback from the pilot leaders.

Data Availability and Reproducibility: A dedicated section was added at the end of the document linking the Zenodo repository and the shared underlying datasets to ensure full research reproducibility.

Any further responses from the reviewers can be found at the end of the article

Introduction

As highlighted by the European Commission (European Commission, 2020), the European building stock is mostly outdated and energy-inefficient. Most buildings date back to periods when energy regulations were less stringent, resulting in high energy consumption and significant environmental impacts. This is a major obstacle to achieving the EU's climate goals of reducing greenhouse gas emissions by 2030 and climate neutrality by 2050. Although renovations of all kinds are carried out in about 11 percent of this stock every year, there is insufficient prioritisation of energy-saving measures. In addition, the deep renovation rate is very low: the annual rate of deep renovations in the EU27 is about 0.2 percent (BPIE, 2021), with relatively small variations among individual Member States. The weighted annual energy renovation rate for residential buildings has been estimated to be close to 1 percent within the EU. This rate is aligned with European Commission estimates (ranging from 0.4 percent to 1.2 percent depending on Member States (Hermelink *et al.*, 2019) and confirms insufficient progress in decarbonising the building stock.

To achieve the ambitious EU decarbonisation goals, the European Union is mildly promoting the deployment of energy positive homes (EPH) through the recently adopted EPBD recast (European Parliament and Council, 2024). Thanks to the integration of innovative technologies and advanced design strategies, EPHs can produce more energy than they consume, and share the surplus clean energy within their district/neighborhood, thus actively contributing to the decarbonisation of the building sector.

However, transition to a sustainable building stock and EPH deployment are hampered by several barriers such as the fragmentation of the renovation/construction processes, which is compounded by the widespread lack of public appreciation of EPHs' long-term benefits. Overcoming these barriers and accelerating the transition to a sustainable building stock calls for an integrated approach involving all stakeholders in the building sector: institutions, businesses, professionals, and citizens.

In this framework, The Horizon Europe POSIFIT Project is a groundbreaking initiative designed to develop and validate a flexible and comprehensive approach to Energy Performance Housing (EPH). This approach is centered on creating smart solutions that are easily adaptable and replicable, aiming to streamline building construction and renovation processes. To this end, POSIFIT offers professionals and end-users an innovative holistic design platform with three main functions: 1) aiding decision-making; 2) assisting in the design process; and 3) establishing an innovative marketplace that enhances communication/experience exchange among stakeholders.

The aim of this paper is to present the results of the analysis of the barriers and drivers identified and mapped throughout the implementation process of EPHs. The identification and mapping activities took three main factors into account: (i) the POSIFIT Pilot Countries (Hungary, Luxemburg, Spain, The Netherlands, and Turkey), (ii) the stakeholders facing or causing the barriers, and (iii) the project phases where the barriers occur. This analysis has provided the POSIFIT Project with the information needed to create suitable services and solutions that can effectively tackle the barriers. A similar methodology was used to identify drivers and how POSIFIT can exploit them. While POSIFIT focuses on specific pilot countries, the barriers and drivers identified are generally relevant to most European countries, which face similar challenges in implementing EPHs due to the complex and fragmented renovation/construction landscape. The Project's findings can inform and guide other initiatives across Europe and help:

- **overcome common challenges.** By analysing barriers and drivers, POSIFIT contributes to a broader understanding of the challenges and opportunities associated with EPH implementation. This knowledge can help other countries and projects overcome common obstacles and accelerate the adoption of EPHs.

- **implement policy recommendations.** The analysis of barriers and drivers can inform policy decisions and strategies at European level, thus leading to the development of supportive policies and frameworks that facilitate the wider implementation of systemic solutions for EPHs.

- **showcase best practice examples.** POSIFIT's approach to identifying and addressing barriers and drivers can provide a best practice example for other EPH projects. This encourages knowledge sharing and promotes the development of effective implementation strategies across Europe.

The analysis of barriers and drivers is essential for the success of POSIFIT and for the broader adoption of EPHs in Europe. By understanding the challenges and opportunities associated with implementing systemic and systematic solutions, stakeholders can develop targeted strategies, overcome obstacles, and promote the effective sustainable use of EPHs.

The main novelty of the POSIFIT approach lies in developing an innovative understanding of EPH and redefining the phases of renovation/new construction processes. Additionally, the POSIFIT approach provides a comprehensive picture of the EPH ecosystem and the key actors by reliably identifying the stakeholders affected by or contributing to the barriers/drivers. Finally, the POSIFIT approach offers targeted suggestions to overcome the challenges of EPH implementation in the different project phases and in diverse contexts.

This paper is structured in four main sections. The first section deals with the theoretical and methodological pillars on which the acceleration of EPH implementation is based, starting from the definition of EPH in the POSIFIT Project context. The paper then explores the research methodology developed to identify and map barriers and drivers in the different real ecosystems. Thirdly, the results of the analysis are presented and the main findings outlined. A specific focus is put on the contribution which POSIFIT potentially gives to tackling the barriers and exploiting the drivers. The final part of the paper summarises the key findings of the analysis, with specific references to the comprehensive implementation of EPHs.

Method

Theoretical and methodological pillars of the analysis

To systematically address the complexities of transitioning to Energy Positive Homes (EPHs), the POSIFIT project adopts a robust methodological framework structured around four interconnected pillars. This framework, illustrated in Figure 1, ensures a holistic approach that integrates technical definitions, process innovation, real-world validation, and stakeholder engagement. Pillar A establishes a common definition of EPHs centered on bioclimatic performance and a staged renovation path. Pillar B redefines the construction and renovation process by incorporating circular economy principles and introducing novel phases such as deconstruction. Pillar C validates this approach across five diverse pilot countries to test adaptability and replicability. Finally, Pillar D fosters a dynamic stakeholder community to co-develop solutions and ensure broad market uptake. This multi-pillar structure provides the foundation for identifying and overcoming the barriers detailed in the subsequent sections.

Pillar A: Developing a common definition of EPH

A comprehensive understanding of the EPH concept is essential to effectively identify and map the barriers and drivers inherent in EPHs. This requires a clear definition of the concept, encompassing its key characteristics and delineating the elements that distinguish it from conventional housing. EPHs represent a significant step forward in sustainable building

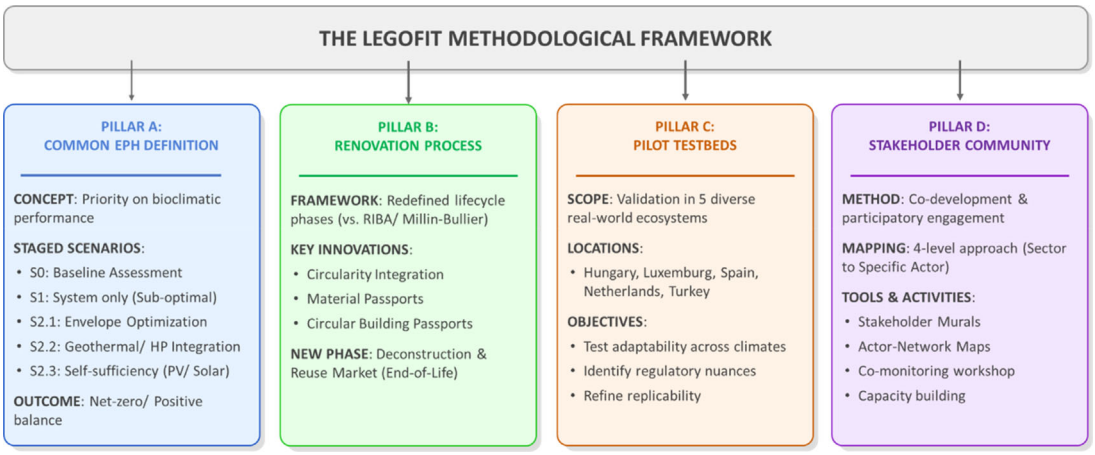

Figure 1. The POSIFIT Methodological Framework. The diagram illustrates the four strategic pillars underpinning the project: A) Defining EPHs through bioclimatic priority; B) Redefining the renovation process with circularity; C) Validating via pilot testbeds; and D) engaging a comprehensive stakeholder community.

design since EPHs use net zero energy and generate excess renewable energy, which in turn will reduce reliance on fossil fuels.

Several definitions of Positive Energy Buildings - PEBs - are available in the literature. (Kumar & Cao, 2021) provide a comprehensive review of the definitions currently available for PEBs. The authors point out that PEBs offer benefits over Net Zero Energy Buildings, including on-site and off-site renewable energy generation, renewable energy credits, reduced carbon and GHG emissions, lower building costs, and support for the utility grid. PEBs are defined using many criteria, including energy, energy, cost, emission, and grid connection. PEB focuses on maximizing energy performance through a systematic strategy, rather than just exporting excess energy and importing shortage.

Ala-Juusela *et al.* (2021a) and Ala-Juusela *et al.* (2021b), provide a full explanation of PEB, first addressing the set of terms used to define NetZEB and PEB principles, and then outlining the technological framework that is employed for the PEB definition. Furthermore, social and human-centric factors, which are not frequently addressed in the literature related to NZEBs and NetZEBs, are taken into consideration in the PEB definition.

Building on the previous definitions of PEBs developed in the framework of EU Projects (Belleri *et al.*, 2023), POSIFIT introduces a new concept of EPHs. This concept underlines the importance of a building's inherent bioclimatic performance, i.e., achieving high energy efficiency 'without touching the button'—meaning without relying on mechanical systems. This foundational principle aligns with the rigorous **Passive House standards**, which advocate for reducing the specific heating and cooling demand to negligible levels through passive measures before any active energy supply is considered (Schnieders *et al.*, 2015). According to extensive reviews on energy-efficient design, the prioritization of the building envelope—incorporating super-insulation, the elimination of thermal bridges, high-performance glazing, and airtightness—remains the most effective method to permanently lower energy loads (Sadineni *et al.*, 2011). Furthermore, bioclimatic strategies such as optimizing solar gains in winter and shading in summer are critical to ensuring thermal comfort without energy input (Pacheco *et al.*, 2012).

POSIFIT operationalizes these theoretical principles through a practical **staged-scenario methodology** that dictates a strict hierarchy of interventions. The project explicitly contrasts a standard 'technological fix' (**Scenario 1**), where an air-source heat pump is installed in an uninsulated building—often resulting in suboptimal performance due to the high flow temperatures required—against a 'deep renovation' path. POSIFIT advocates for **Building Envelope Optimisation (Scenario 2.1)** as the absolute prerequisite step. By first minimizing the building's thermal needs, the project ensures that subsequent mechanical systems, such as the transition to high-efficiency geothermal heat pumps (**Scenario 2.2**), can be significantly downsized and operated at lower temperatures, thus maximizing the seasonal performance factor (SPF) and creating a virtuous cycle of energy reduction.

To effectively implement the bioclimatic performance principle, POSIFIT focuses on a staged-scenario approach as reported in Miguel Mitre, 2023, which can be applied not only to building renovation but also to new construction projects. This staged conceptual approach which can also be concretely implemented consists of three scenarios progressively driving the building towards net-zero energy consumption or even surplus energy production, as follows:

- Scenario 0 is the baseline state of play scenario.
- Scenario 1 is the most usual solution, only involving mechanical equipment improvement.
- Scenario 2 proposes the most effective stage sequence to achieve energy self-sufficiency.

Scenario 0: Baseline Assessment (Figure 2).

This stage represents the building's initial energy consumption profile. It serves as a benchmark against which improvements can be measured.

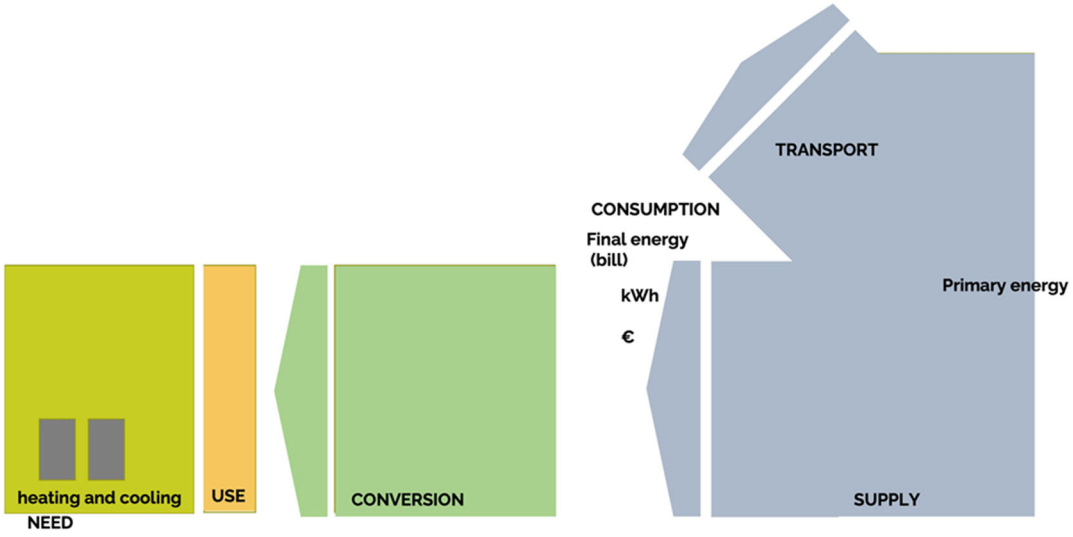

Figure 2. Baseline - Adapted from the literature. This figure has been reproduced with permission from Miguel Mitre (2023).

Scenario 1: Improvement of the heating system (Figure 3).

Figure 3 shows the improvement of the building's heating system addressed alone by installing an air-source heat pump, without taking the envelope optimisation into account first. Although an improvement on the baseline scenario is shown, with a reduction of primary energy, this is not the most efficient way to achieve overall building energy efficiency.

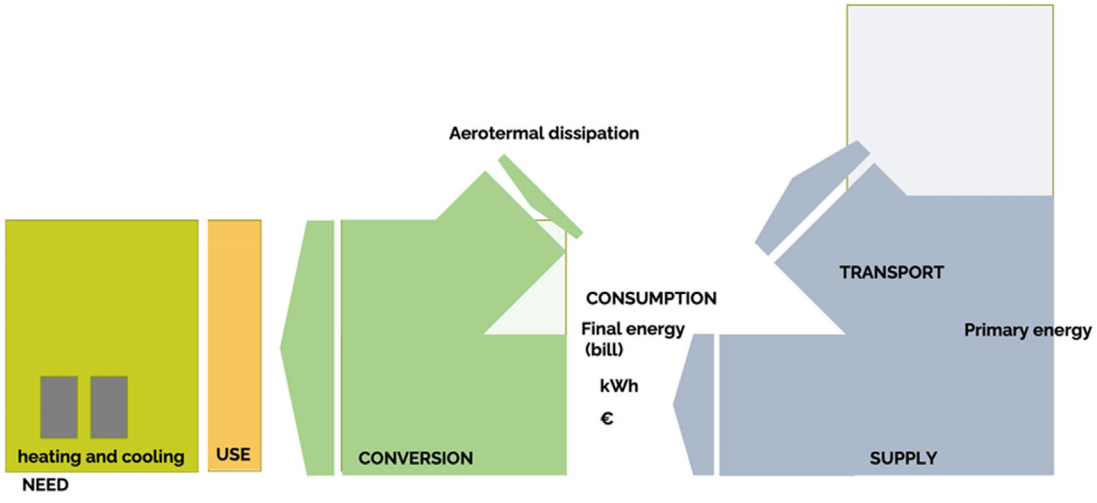

Figure 3. Installation of an aerothermal heat pump - Adapted from the literature. This figure has been reproduced with permission from Miguel Mitre (2023).

Scenario 2.1: Building Envelope Optimisation (Figure 4).

On the other hand, if improvements are first carried out on the building envelope, the building's heating and cooling needs are reduced. Next, the aerothermal heat pump system is installed and the user is trained in optimal operation, thus leading to lower energy demand, and hence, consumption, as shown in the following figures.

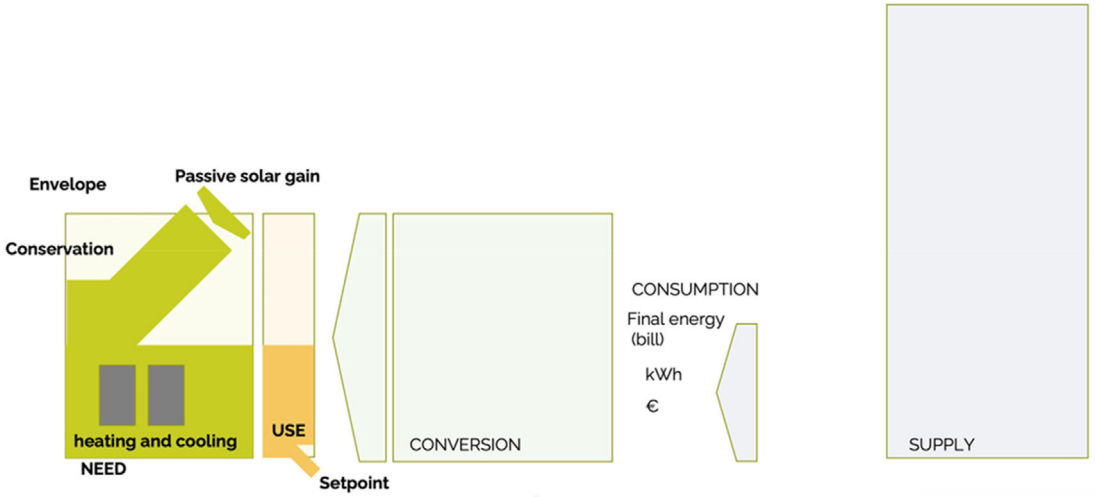

Figure 4. Key aspect: optimisation of the envelope before the installation of an aerothermal heat pump - Adapted from the literature. This figure has been reproduced with permission from Miguel Mitre (2023).

Scenario 2.2: Heat pump optimization (Figure 5).

The top efficiency level of the building itself is achieved when the air-source heat pump is replaced with a ground-source geothermal heat pump. In this way, the external energy supply dependence can be further reduced, since geothermal systems offer higher efficiency due to the stable ground temperature, and the primary energy required is limited (Figure 3 compared to Figure 4). In addition, geothermal systems have a low heat island effect, which creates a virtuous circle around the building.

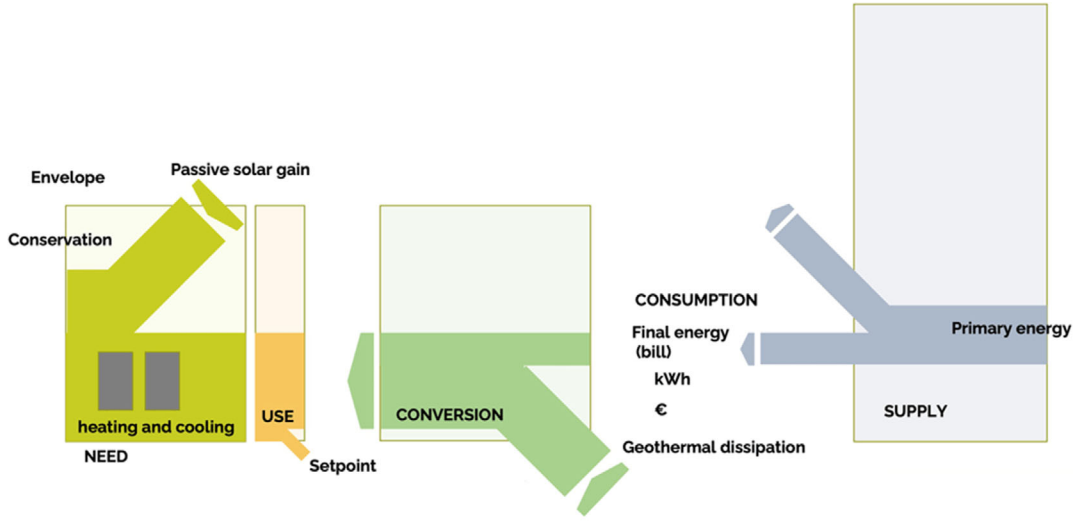

Figure 5. Installation of a geothermal heat pump in addition to optimisation of the envelope & building use - Adapted from the literature. This figure has been reproduced with permission from Miguel Mitre (2023).

Scenario 2.3: Achieving Self-Sufficiency (Figure 6).

Finally, in this final stage (Figure 6), the potential for self-sufficiency emerges, as installing thermal solar/PV systems can enable users to achieve a net-zero or even a positive energy balance.

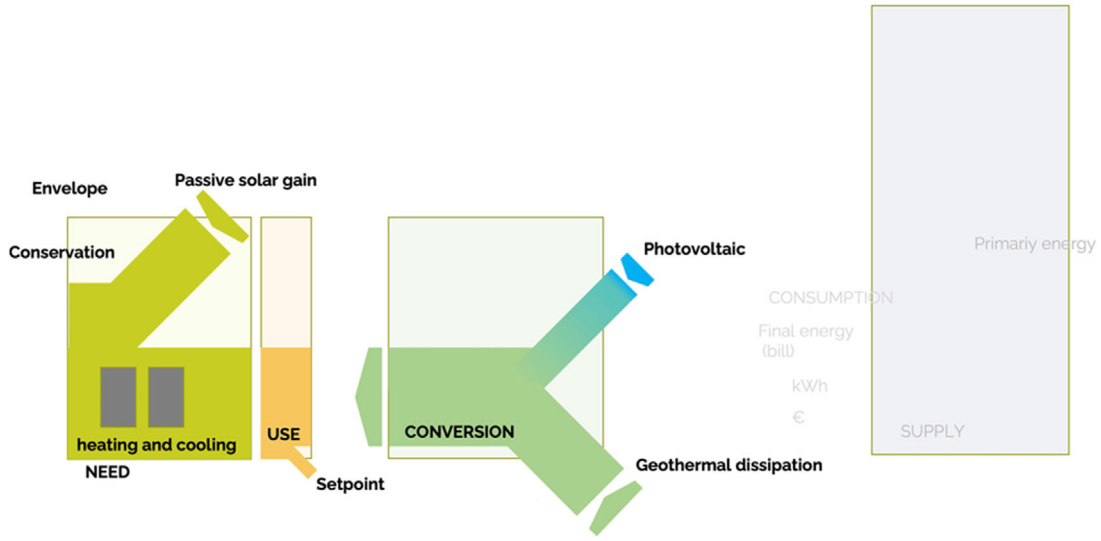

Figure 6. Solar energy (PV) in addition to installation of a geothermal heat pump in addition to optimisation of the envelope & building use - Adapted from the literature. This figure has been reproduced with permission from Miguel Mitre (2023).

By following this step-by-step approach, building renovations can achieve significant energy savings and progress towards net-zero or positive energy goals. The key takeaway is the logical order of interventions:

- Optimise the building envelope to minimise energy demand.
- Right-size the heating system based on the reduced demand.
- Integrate renewable energy sources to further reduce reliance on external energy.

Pillar B: Defining the Construction/Renovation Process Phases

EPH implementation is essential to boost energy efficiency, lower CO_2 emissions, and improve living conditions. However, EPHs are hampered by different obstacles. To successfully overcome these obstacles an extensive understanding of the renovation and new construction process phases is required since each phase of the process poses different problems. Building on established expertise and frameworks such as the (Milin & Bullier, 2021; RIBA Architecture, 2020; Laghi *et al.*, 2021), this granular approach allows for a thorough definition of the renovation/new construction process phases. A key innovation of POSIFIT lies in integrating circularity principles into the process phases. By incorporating tools like the material passport and a dedicated end-of-process phase, the Project promotes material reuse and recycling, thus enhancing the EU decarbonization efforts. This comprehensive methodology is detailed in Table 1 by comparing the POSIFIT approach with traditional approaches like the RIBA Plan of Work and the Millin Bullier research.

POSIFIT not only streamlines the renovation process but also offers a valuable model for new construction projects, thus providing a robust and adaptable framework and contributing to the advancement of sustainable and energy-efficient building practices.

Table 1. **Comparison between the RIBA Plan of Work, the Millin Bullier, and the POSIFIT Approach.**

RIBA	MILLIN/BULLIER	POSIFIT on the basis of the EOS practice and experience
01|DEMAND GENERATION		
	1. INFORMATION/ MARKETING	Information/marketing
	2. DETECTION	Detection
		Designer - client relationship establishment
		Initial information input
02| DIAGNOSIS		
	3. SIMPLIFIED DIAGNOSIS AND RECOMMENDATIONS	
STRATEGIC DEFINITION (clients requirement confirmation)		Final specification definition
	6. FINANCING PLAN	First Financial plan
PREPARATION AND BRIEFING		Diagnosis, viability and alternatives
		Form, performance and cost agreement
03| DESIGN		
	5. SELECTION OF COMPANIES	Preselection of providers
CONCEPT DESIGN	**4. PROJECT DESIGN**	Preliminary or concept design
SPATIAL COORDINATION		Grants application
		Grants awarding
		Community contract confirmation
		Schematic or basic design
		Building permit application
	7. FINANCING SOLUTIONS	Financial plan confirmation
TECHNICAL DESIGN		Detailed, technical or executive design
04| INTERVENTION		
MANUFACTURING AND CONSTRUCTION	**8. RENOVATION WORK**	Building permits confirmation
		Operative financing
		Insurance
		Final Providers selection
		Builder selection
		Builder contracting
		Site preparation
		Manufacturing
		Construction (Intervention itself)
	9. WORKSITE SUPERVISION/ RECEPTION OF THE WORK	Construction management and supervision

Table 1. *Continued*

RIBA	MILLIN/BULLIER	POSIFIT on the basis of the EOS practice and experience
		Commissioning
		Documentation
HANDOVER		Reception of the building
		Legalisation
		Other administrative procedures
05| OPERATION		
USE	**10. QUALITY ASSURANCE, GUARANTEES AND FOLLOW-UP**	Occupation
		Operation startup
		Energy management
		Operation optimisations
		Occupancy satisfaction
		Operation results confirmation
		Normalised operation
		Maintenance
06| REPLICATION		
		STEPPED POSITIVE ENERGY TRANSITION
		Deconstruction & Reused Materials and Components Market: This final, long-term phase focuses on the building's future. Deconstruction, a sustainable dismantling approach, involves carefully taking apart the building at the end of its lifespan.

Pillar C: Activating Different Testbeds to Demonstrate the POSIFIT Viability

A key component of the POSIFIT approach is the implementation of the Project across diverse pilot contexts - Hungary, Luxembourg, Spain, The Netherlands, and Turkey. These pilots provide real-world test cases, demonstrating the adaptability and effectiveness of the POSIFIT framework across contexts characterised by different geographical locations, regulatory environments and Project scales. Therefore, findings from these pilot projects provide valuable feedback on common and specific barriers/drivers, allowing the refinement of the framework applicability and replicability across a wider range of contexts.

Pillar D: Setting up the POSIFIT Stakeholder Community

This pillar focuses on establishing a community of stakeholders involved in the building renovation/new construction process. The POSIFIT Stakeholders' Community aims to bring together diverse stakeholders, including local pilot actors, technology providers, public authorities, and research organizations, to connect the project with replication areas and the EU market. By bringing together diverse perspectives, the POSIFIT process aims to identify and address potential barriers and drivers related to energy-efficient building practices. This collaborative approach ensures that the POSIFIT solutions are practical, relevant, and widely applicable.

The members of the POSIFIT Stakeholders Community belong to a wide variety of backgrounds, namely:

- local pilot players, including government agencies, utility businesses, technology suppliers, and research groups that are directly associated with the POSIFIT pilot initiatives.

- professionals in the construction value chain, including contractors, architects, engineers, and material suppliers.

- researchers and academics, including experts in energy efficiency, building technology, and sustainable construction.

- end users and citizens e.g. people who live in energy-positive buildings.

The stakeholders of the POSIFIT Community were identified according to the four-level approach devised within AÚNA, The Spanish permanent multilateral Smart Finance FORUM for Smart Buildings, Coordinated by Emilio Miguel Mitre on behalf of GBCE. EU's Horizon 2020 Coordination and Support Action project# 957119 (November 2020 to October 2022). One example is the institutional side:

- FIRST LEVEL (SECTOR): Public Sector

- SECOND LEVEL (SUBSECTOR): Administration

- THIRD LEVEL (CATEGORY): Central government

- FOURTH LEVEL (SUBCATEGORY): Republic of Turkey Ministry of Environment, Urbanisation and Climate Change

POSIFIT uses a two-step process to map the stakeholders and interact with them in an efficient way. The first step consists in devising stakeholder murals identifying important stakeholders in each pilot project, and showing their responsibilities, industries, and contact details. The second step is based on actor-network maps illustrating the stakeholder connections.

Each stakeholder is essential to the POSIFIT project's success. The community fosters collaboration and knowledge exchange through activities like webinars, workshops, and training sessions. It encourages such as the adoption of EPH solutions by sharing best practices, addressing common challenges, and promoting innovative approaches across sectors.

During workshops and events Figure 7 held throughout the POSIFIT project lifetime, key stakeholders are expected to actively participate in sharing, debating, and presenting their experiences and resources. Written informed consent was obtained from each stakeholder in the community'. They gave consent for the collection, recording, processing, storage and transfer of personal and sensitive personal data within the framework of the POSIFIT project (Grant Number: 101104058). Members of the community put forward discussion points and share the main obstacles/drivers, give feedback on the POSIFIT platform, increase awareness and spread information, thus promoting the POSIFIT project.

POSIFIT methodology for identifying and mapping barriers and drivers toward EPH in the pilot countries

To address the complex challenges of EPH implementation, the POSIFIT Project employs a comprehensive methodology in four main steps, shown in and described below (Figure 8).

Setting up the framework

Firstly, a structured *framework* was devised to categorize and map the barriers and drivers identified within the POSIFIT project. The barriers and drivers were analysed based on the features listed in Table 2.

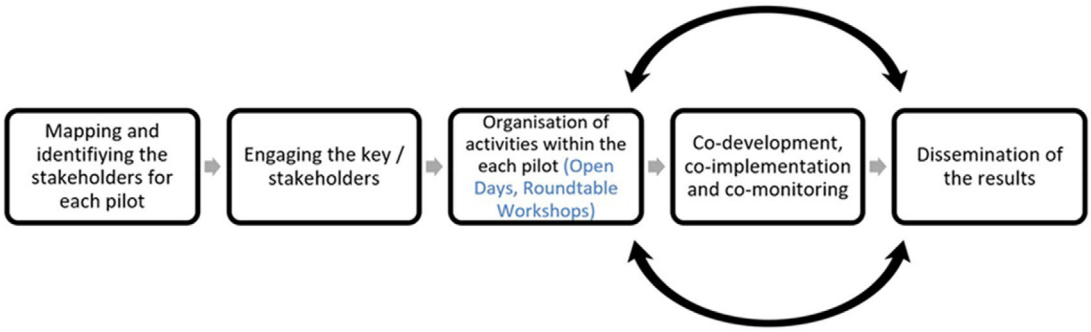

Figure 7. Mapping of the activities of the POSIFIT Stakeholder community.



Figure 8. Methodology to identify and map barriers and drivers towards EPH in the POSIFIT Project.

Table 2. Features of the barriers and drivers analysed within POSIFIT.

BARRIERS	DRIVERS
Categorisation | Classification of the barrier based on its inherent nature, such as technical, regulatory, financial, or social.	**Categorisation** | Classification of the driver based on its inherent nature, such as technical, regulatory, financial, or social.
Description | Detailed characterization of the barrier, outlining its key features, potential consequences, and its influence on project outcomes	**Description** | Detailed characterization of the driver, outlining its key features, potential consequences, and its influence on project outcomes
Contextual Factors | Identification of any geographical, cultural, or project-specific factors that may influence the manifestation or severity of the barrier.	**Contextual Factors** | Acknowledges the unique context of the pilot project locations and their role as crucial testing grounds for proposed solutions.
Stakeholder Category | Determination of the stakeholders affected by or contributing to the barrier, enabling the identification of those requiring support or potentially hindering progress	**Stakeholder Category** | Specifies the stakeholder groups who are positioned to leverage the identified driver to their advantage.
Phase of Occurrence | Assessment of the barrier's impact relative to the project lifecycle, categorizing it based on the stage where its influence is most pronounced (e.g., design, implementation, operation).	**Phase of Occurrence** | Determines the specific project phase(s) in which the influence of the driver is most pronounced and when the driver can be effectively exploited at most
Project Contribution | Evaluation of the project's potential to address the barrier through targeted interventions and solutions.	**Project Contribution** | Explicates how the project can provide enhanced support to stakeholders in effectively capitalizing on the identified driver. This encompasses the design and refinement of services or solutions that facilitate the optimal utilization of the driver's potential. Furthermore, it underscores the project's role in amplifying driver exploitation to achieve augmented project outcomes and maximized benefits for all stakeholders.
Scope of Applicability | Determination of the barrier's relevance to standard project practices versus its specificity to projects with ambitious objectives or innovative approaches.	**Scope of Applicability** | Determination of the driver's relevance to standard project practices versus its specificity to projects with ambitious objectives or innovative approaches.

By employing this comprehensive framework, the POSIFIT project gains a deeper understanding of the barriers and drivers that will influence its implementation. This knowledge allows for the development of targeted interventions and solutions that will maximise the Project's positive impact while mitigating potential challenges.

Data collection

The data was collected in two main steps: literature review and collaborative mapping workshop with Pilot Leaders.

Firstly, the POSIFIT Project Partners, in particular the Pilot Leaders, carried out a comprehensive review of existing literature, encompassing research papers (D'Oca & op't Veld, 2018; European Environment Agency, 2023; Kangas *et al.,* 2018; Lassandro *et al.,* 2024) and reports developed within the framework of ongoing and past EU projects focused on building renovation and construction. This extensive research allowed the Consortium to gain an overview of established/innovative methodologies and best practices in building renovation/new construction processes and to be reliably informed about obstacles and challenges that may hinder the successful implementation of EPHs.

Secondly, the profiling of the barriers and drivers was completed by directly involving the POSIFIT Pilot Leaders in a collaborative two-day mapping workshop. The workshop allowed the Consortium to validate the barriers and drivers identified through the literature analysis and to identify further barriers and drivers in the POSIFIT Pilot Countries. It was also possible to collect suggestions for exploiting the potentialities/drivers and overcoming the barriers.

The methodology of the workshop was a brainstorming session, conducted by employing a Mural Online Platform with virtual sticky notes (Figure 9 and Figure 10) to represent the barriers and drivers identified within the framework established in the previous paragraph. This visual representation facilitated the identification of clear relationships and potential cause-and-effect chains between the identified factors.

Data analysis

The project partners' productive collaboration during the workshop enabled the Consortium to effectively launch into the analysis phase of the barriers and drivers. This early start facilitated a comprehensive assessment and allowed categorising and prioritising the barriers/drivers based on their impact and potential for intervention. Following the workshop, a qualitative analysis was conducted to select the most frequent barriers/drivers and delve deeper into the insights collected from the brainstorming notes. This analysis provided the Consortium with valuable insights

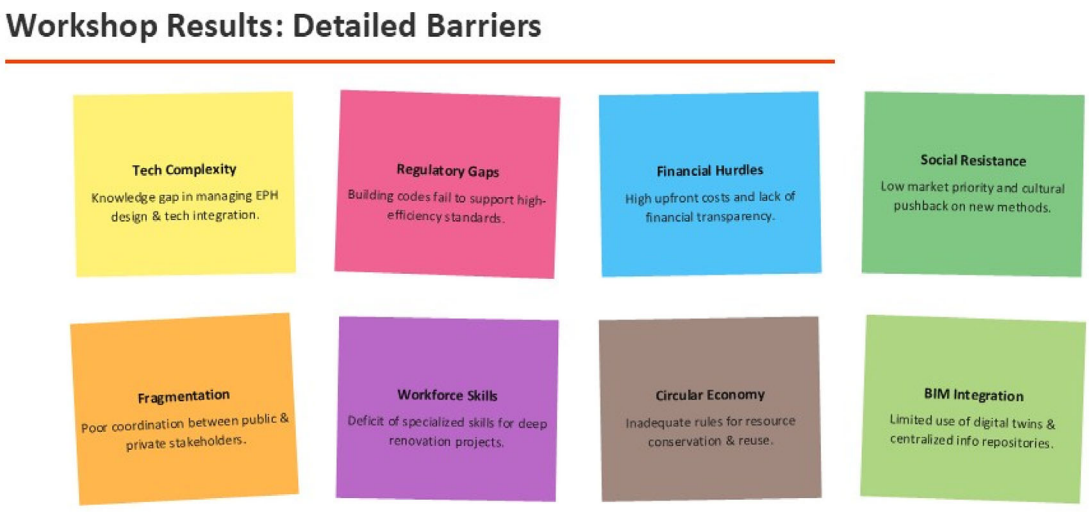

Figure 9. Barriers identified for each POSIFIT Pilot Country- Mural Platform Screenshot. The figure was prepared by the manuscript authors in response to feedback from the pilot leaders.

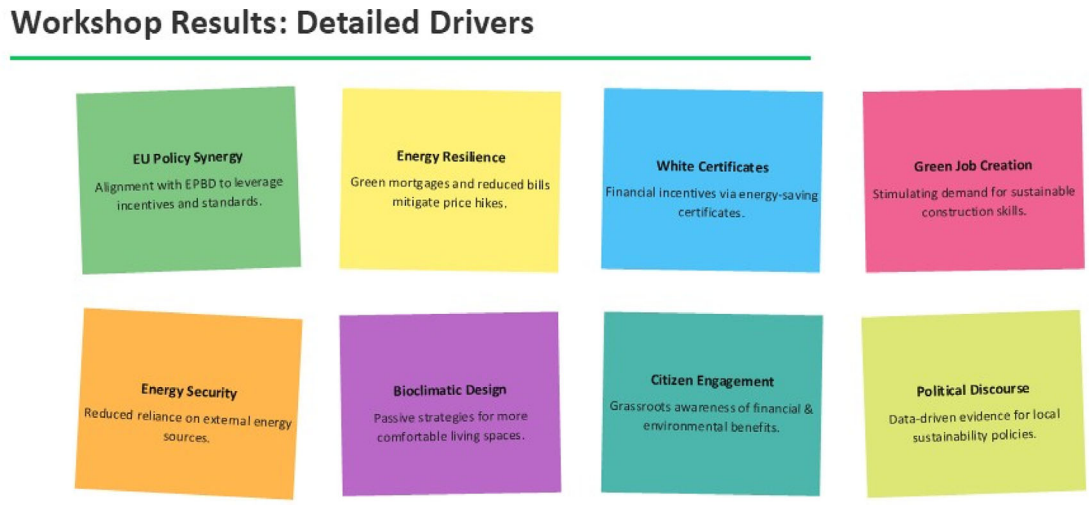

Figure 10. Drivers identified for each POSIFIT Pilot Country - Mural Platform Screenshot. The figure was prepared by the manuscript authors in response to feedback from the pilot leaders.

into the recurring key themes and the challenges behind the identified barriers and drivers, leading to more informed decision-making.

Validation and refinement

Following the collaborative workshop, the resulting Mural template was disseminated to all the Project partners for feedback and refinement. This key validation step ensured that the collected data accurately reflected the broader Project context and addressed potential blind spots. The following paragraph illustrates the outcomes of the validation phase.

This four-step POSIFIT methodology provided a comprehensive approach which combines the outcomes of the literature research with real-life implementation. This knowledge about barriers/drivers can then be used to effectively develop targeted interventions and strategies for optimizing project outcomes, thus enhancing efficiency, and ultimately contributing to a more successful and sustainable built environment. Moreover, the methodology offered by POSIFIT is adaptable, since it was implemented in very different renovation/new construction processes and contexts of the Pilots.

Results and discussion

This part of the paper focuses on the potential contributions that POSIFIT offers to tackle the barriers and leverage the drivers characterising the extremely complex and fragmented renovation/new construction processes.

Technical barriers

Homeowners and asset owners are the stakeholders worst affected by technical barriers in deep renovation/new construction projects, particularly those aimed at implementing EPHs. This is due to limited awareness of the substantial benefits of highly efficient buildings (i.e. sustainable building does not occupy a high position in their interest rank) and a lack of the necessary knowledge to face the complexities of the process. While the design phase presents the most significant technical barriers to energy-efficient housing, the approaches of public institutions, financial institutions, and the construction industry could inadvertently amplify these challenges. Aligning energy efficiency targets with feasible solutions and equipping the workforce with the necessary skills will be crucial for advancing the adoption of energy-efficient housing solutions.

The POSIFIT project aims to accelerate the transition towards EPHs by addressing key technical barriers hindering the EPH widespread adoption through a multi-faceted approach encompassing the following three main strategies.

1. Enhancing Innovation - BIM Integration, Digital Twins and Open Innovation Community

BIM Integration and Digital Twins. POSIFIT utilises Building Information Modeling (BIM) and Digital Twin technology to create a holistic digital representation of buildings. This improves decision-making throughout the building lifecycle, addresses knowledge gaps by providing a centralised information repository, and enables detailed renovation designs.

Open Innovation Community - The Open Innovation Community is part of the POSIFIT stakeholder Community and fosters collaboration amongst Building Energy Management (BEM) professionals. This platform facilitates knowledge sharing, accelerates the development of innovative solutions, and promotes best practices within the EPH sector.

2. Improving Efficiency

Streamlined Data Aggregation - The POSIFIT platform addresses data fragmentation issues by streamlining data aggregation from the different sources relevant to the renovation/new construction process. This centralised approach provides a comprehensive understanding of building performance, leading to more informed decision-making and cost optimisation.

3. Upskilling

Targeted Training Programs - To address the shortage of skilled professionals in the BEM sector, POSIFIT provides ad-hoc training for both industry professionals and construction workers. This upskilling initiative aims to bridge the skill gap and equip the workforce with the expertise needed to effectively implement and manage energy-efficient technologies.

4. Improving Collaboration Among Stakeholders

POSIFIT Stakeholder Community - POSIFIT establishes a dedicated Stakeholder Community to foster collaboration amongst the diverse actors involved in the building lifecycle, including architects, engineers, contractors, and building owners. This collaborative approach ensures alignment on project goals, facilitates effective communication and promotes coordinated action towards EPH implementation.

Regulatory barriers

Both homeowners and professionals across the construction value chain experience adverse effects. These regulatory barriers affect all stages of renovation and construction projects, with the design phase being particularly impacted.

Regulatory constraints in the building sector substantially hinder the deployment of energy-efficient approaches, limiting market development.

Using a three-pronged strategy, POSIFIT promotes a proactive approach to tackle regulatory barriers hampering the implementation of EPHs by:

1. advocating for improved regulations and incentives – Since inadequate rules and limited incentives hinder the adoption of sustainable building techniques, POSIFIT promotes the implementation of higher energy efficiency standards, resource conservation, and circular economy concepts in building codes and regulations to enhance sustainability.

2. recommending regulatory improvements - By leveraging real-world data and stakeholder input, the project identifies areas for regulatory improvement and proposes concrete changes in order to:

    - streamline permit processes - Promoting best practices can simplify application procedures, reduce bureaucratic hurdles, and accelerate approval timelines for sustainable building projects.

    - address regulatory constraints on renewable energy sources - POSIFIT identifies and fosters the adoption of best practices for regulatory barriers that specifically hinder the integration of renewable energy technologies in buildings

    - promote retrofitting vs new construction - POSIFIT advocates for regulations that encourage and incentivise the renovation of existing buildings rather than new construction.

3. Promoting reuse and recycling of resources – POSIFIT champions the development of effective regulations and certifications for re-used and recycled building materials, namely:

    - Material Passports - Documents that provide detailed information about the composition, origin, and environmental impact of building materials, facilitating their reuse and recycling.

    - Circular Building Passports - Comprehensive documents that track the lifecycle of building materials and components, enabling their reuse and repurposing in future construction projects.

Financial barriers

Financial barriers adversely affect all the stakeholders involved in the EPH retrofitting/construction value chain and hamper the whole process of renovation/construction. These barriers, already present in standard renovation/new construction processes, are amplified in EPH interventions, which are inherently more complex.

The POSIFIT innovative platform aims to address the manifold financial barriers to EPHs by promoting cost reduction, enhancing financial transparency, fostering suitable business models, and encouraging a circular economy. The POSIFIT strategy is founded on four main pillars.

1. Promoting Cost Reduction for Technology and Services

The POSIFIT Platform counters the high costs of new technologies, services, and solutions associated with EPHs by conducting technical and financial assessments to identify cost-effective options, facilitating access to affordable efficient technologies, and promoting the use of standardised solutions to reduce implementation costs.

2. Enhancing Clarity and Potential Cost Reduction for EPHs

The POSIFIT Platform addresses the lack of transparency regarding the costs and benefits of EPHs by promoting transparency in pricing and financing options. In addition, POSIFIT offers clear information on the long-term financial benefits of EPHs and explores potential ways to decrease the additional costs associated with EPHs, particularly those related to longer payback periods. This increased transparency enables stakeholders to make informed decisions and potentially reduce costs associated with EPHs.

3. Overcoming the Lack of Suitable Business Models

POSIFIT tackles the lack of suitable business models for EPHs and of financial space for Positive Energy Districts (PEDs) by replicating successful existing business models for renovations to demonstrate the financial viability of interventions. POSIFIT also implements crowdfunding, which can be used alone or in association with existing business models to unlock alternative funding sources for building intervention. In any standard renovation intervention, the cost of the works is expected to produce a value increase of the home at least equal to the renovation cost. If it is an energy renovation, the value will evolve better in the future. This is less clear so far. Regarding the EPH interventions, the additional cost to achieve a positive balance does not yet have financial mechanisms to make it desirable.

4. Promoting Circular Economy and Material Reuse

Since the construction industry generates significant waste and contributes to environmental concerns, POSIFIT promotes a circular economy approach by introducing Material Passports and Circular Building Passports to track and facilitate material reuse. The combined action of the POSIFIT Platform, relevant marketplace and stakeholder community makes it possible to foster a reduction in the price of circular products through increased demand and accessibility. The synergy of the three POSIFIT tools also facilitates reselling reused/recycled materials and components, thus creating a secondary market.

Social barriers

Social barriers in the EPH processes affect homeowners, asset owners, and, more generally, citizens. These barriers, already present in standard renovation/new construction throughout the process, are amplified in EPH interventions, inherently more complex and requiring additional upfront money. The POSIFIT approach to tackling social barriers is based on five main tools.

1. User-Friendly Platform

The POSIFIT Platform offers users tailored solutions based on individual needs, clearly presents the potential benefits/costs of EPH, and provides the necessary information for informed decision-making.

2. Resident-Centred Crowdfunding

POSIFIT fosters a sense of community ownership and participation through resident-centred crowdfunding. This initiative involves residents directly in the financing of retrofitting/new construction projects, fostering a sense of collective responsibility and leading to greater acceptance of EPHs. By providing an alternative financing mechanism, POSIFIT makes EPH retrofits more accessible to a wider range of residents.

3. POESY Tool

POSIFIT employs the POESY tool to bridge the gap between theoretical predictions and actual user experience. POESY gathers real-time occupant feedback on comfort levels, thus allowing discrepancies between expected and actual performance to be addressed. By ensuring that EPHs meet the comfort and well-being needs of occupants, POSIFIT builds trust and confidence in EPH technology.

4. POSIFIT Stakeholder Community

The POSIFIT stakeholder community plays a key role in fostering a collaborative environment which accelerates the widespread adoption of EPHs. The Community facilitates communication and collaboration among key stakeholders and provides a platform for exchanging information, best practices, and lessons learned, thus creating a supportive network for individuals and professionals.

5. Targeted and Accessible Training

POSIFIT provides comprehensive training to ensure that stakeholders have the necessary knowledge and skills to implement EPHs effectively. Conducted with the support of the POSIFIT Pilot leaders, these programs meet the specific needs of the different stakeholders, employ diverse formats and channels to reach a wide audience, and offer practical insights through real-world examples.

Drivers

The paper goes on to analyse the role external drivers, namely regulations, incentives, and social enablers, can play in supporting stakeholders' decisions regarding EPH. It highlights how these factors can be exploited by the POSIFIT Project, thus driving innovation within EPH implementation.

Regulatory drivers

Regulatory drivers can be exploited throughout the renovation/new construction of EPHs, especially in the design and operation phase. By integrating a systematic methodology for energy and financial analysis into a holistic platform, POSIFIT can effectively exploit the following drivers:

1. Anticipating Carbon Footprint Regulations

POSIFIT anticipates future regulations on carbon footprints for buildings. The POSIFIT platform allows assessing and optimising the carbon footprint of new constructions and renovations. This proactive approach supports the design of energy-efficient buildings that comply with future carbon regulations. By integrating carbon footprint analysis into the design phase, POSIFIT enables stakeholders to make informed decisions that minimise environmental impact.

2. Rolling out Eco-Friendly Materials

POSIFIT incorporates the wide use of eco-friendly materials into design and operational recommendations. This ensures that the Project aligns with existing and future regulations promoting environmentally responsible practices.

3. Addressing Forthcoming Minimum Energy Performance Standards

POSIFIT proactively addresses forthcoming minimum energy performance standards by designing homes that meet the EU requirements in advance. This forward-thinking approach ensures that buildings designed using POSIFIT comply not only with current regulations but also with future energy efficiency requirements.

4. Leveraging Legally Enforced Performance Monitoring

The POSIFIT platform enables continuous tracking and optimization of building performance, thus facilitating compliance with legally enforced performance monitoring requirements. By providing tools for real-time data collection and analysis, POSIFIT allows building operators to address performance gaps, ensuring that buildings meet regulatory requirements throughout their lifecycle. This data-driven approach promotes transparency and accountability in the building operational phase.

Financial drivers

Driven by factors like the European Green Deal and stricter building codes, EPHs offer a wealth of opportunities for various sectors, including finance, design, and energy, while providing homeowners with cost savings, enhanced comfort, and environmental benefits. This transition fosters a mutually beneficial environment where all stakeholders can contribute to and profit from a more sustainable future. The POSIFIT project is strategically positioned not only to address the growing need for EPHs but also to capitalise on several key financial drivers. By integrating a systematic methodology for energy and financial analysis into the POSIFIT comprehensive platform, POSIFIT aims to accelerate the transition towards sustainable and financially viable housing solutions.

The POSIFIT Platform supports the exploitation of the following financial drivers:

1. Capitalising on the Green Economic Deal

POSIFIT aligns with the sustainable investment priorities of initiatives like the European Green Deal. This strategic alignment allows POSIFIT to attract green financing opportunities and leverage public funding for sustainable development.

2. Exceeding Mortgage Portfolio Standards Related to Energy Performance

POSIFIT designs homes that meet and exceed existing energy performance requirements. Besides ensuring compliance with current regulations, POSIFIT homes potentially qualify for preferential mortgage terms or green mortgages, improving access to financing for homeowners and increasing the desirability of these properties.

3. Mitigating the Impact of High Energy Prices

In the context of rising energy costs, POSIFIT promotes energy-efficient home designs and technologies that minimise energy consumption. This results in reduced energy bills for homeowners and increased resilience against fluctuating energy prices. By mitigating the financial burden of high energy costs, POSIFIT makes EPH more appealing to potential homeowners and contributes to long-term cost savings.

4. Benefitting from Preferential Pricing for White Certificates

POSIFIT incorporates bioclimatic principles into home designs, creating more comfortable and energy-efficient living spaces. This focus on passive design strategies and renewable energy sources enables POSIFIT homes to qualify for white certificates (energy-saving certificates). White certificates can be traded for financial incentives, providing an additional revenue stream and further enhancing the financial viability of EPH.

Social drivers

By incorporating a systemic methodology for energy and financial analysis, the POSIFIT platform is well-equipped to exploit the following social drivers and contribute to a more sustainable and resilient built environment.

1. Fostering Green Job Creation

By promoting EPH and supporting the development of the related industries, POSIFIT stimulates demand for sustainable construction practices and technologies, thus contributing to the creation of green jobs within the building sector.

2. Elevating Sustainability in Political Discourse

POSIFIT provides cities with concrete data and evidence of the benefits of EPH, empowering local authorities to make informed decisions and prioritise sustainability in their policies and initiatives. By showcasing the tangible advantages of EPH, POSIFIT helps elevate sustainability to a prominent position in political discourse, encouraging policymakers to adopt effective regulations and incentives.

3. Increasing the Appeal and Desirability of EPH Leveraging Citizen Engagement Towards Sustainability

POSIFIT actively engages citizens by demonstrating the tangible financial and environmental benefits of EPH. POSIFIT raises awareness and showcases successful examples, encouraging individuals to adopt sustainable practices in their own homes and communities. This grassroots approach fosters a sense of collective responsibility and allows citizens to become active participants in the transition toward a more sustainable future.

4. Encouraging the Adoption of Sustainable Practices

POSIFIT provides transparent and reliable data to support informed decision-making, demonstrating the financial viability and long-term value of sustainable practices and contributing to a shift towards a more sustainable construction industry.

5. Contributing to Energy Security and Independence

POSIFIT contributes to increased energy security and independence at both the community and national levels by promoting EPHs that reduce reliance on external energy sources. EPH implementation reduces vulnerability to energy price fluctuations and geopolitical instability, leading to enhanced resilience and self-sufficiency in energy production.

Conclusion

The analysis highlights a multifaceted landscape of barriers and drivers influencing the adoption of EPHs across pilot countries. Common challenges, such as technical complexity and financial constraints, are particularly pronounced in projects targeting ambitious high-efficiency goals. These obstacles primarily affect stakeholders directly involved in the renovation or construction process, including contractors, architects, and homeowners.

The POSIFIT Platform offers a comprehensive solution to tackle these challenges. It provides tailored financial and technical feasibility assessments for innovative solutions, leveraging Building Information Modeling (BIM) to enhance design and collaboration. A key component of the platform is the Stakeholders Community, a vibrant network of diverse stakeholders, including local technology providers, industry professionals, researchers, decision-makers, and citizens. This community fosters knowledge sharing, idea exchange, and the validation of the platform's effectiveness through talks, discussions, and events.

The analysis of drivers suggests that regulatory, financial, and social factors will primarily benefit service/solution providers and homeowners. POSIFIT contributes by introducing a systematic methodological approach for energy and economic analysis, raising awareness of EPH benefits, and promoting efficient resource utilization throughout the renovation/construction process. By addressing barriers and leveraging drivers, POSIFIT aims to accelerate the adoption of EPH and contribute to a more sustainable built environment.

Consent

Written informed consent was obtained from each stakeholder in the community'. They gave consent for the collection, recording, processing, storage and transfer of personal and sensitive personal data within the framework of the POSIFIT project (Grant Number: 101104058).

Data availability

Underlying data

ZENODO: POSIFIT Pilot Questionnaire and Renovation Process Phase Allocation. https://zenodo.org/records/14808944?preview=1&token=eyJhbGciOiJIUzUxMiJ9.eyJpZCI6ImQ4NDQ4NmZiLTFiMmQtNGQ4NS1iZjhmLTA1ZWJiODEyMzA2YiIsImRhdGEiOnt9LCJyYW5kb20iOiJlMjgxNjdkYmU4N2NkN2ViMDZiMGI3NzRmZDQ5MTVmNiJ9.Ae_t3Fk_SVbBIgO8yF2_G--Qbc8OEHs8kb74nD0WvdWdy1ZOmwzlw2kkwFRvNH53v1yucvXjPc9LG_0RjWJczg, Doi: https://doi.org/10.5281/zenodo.14808944 (De Aloysio, 2025).

This project contains the following underlying data:

- POSIFIT_Pilot_Questionnaire.xlsx
- New-renovation phase allocation.xlsx

Data is available under the terms of the Creative Commons Attribution 4.0 International.

Acknowledgement

We hereby declare that this work has not been published elsewhere, nor is it currently under consideration for publication in any other form.

During the preparation of this manuscript/study, the authors used Gemini Pro Version 3.1 for the purposes of improving both the readability and grammar of the paper. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

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Open Peer Review

Current Peer Review Status: ? ?

Version 1

Reviewer Report 06 January 2026

https://doi.org/10.21956/openreseurope.20546.r64768

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This article presents the outcomes of the Horizon Europe **LEGOFIT project**, which aims to accelerate the adoption of **Energy-Positive Homes (EPHs)** through a holistic and integrated approach. The study develops and applies a **four-pillar framework** focusing on (i) redefining EPHs with an emphasis on bioclimatic performance, (ii) restructuring renovation and construction process phases with embedded circular economy principles, (iii) validating the approach across five European pilot countries, and (iv) activating a multi-actor stakeholder community. Using a combination of literature review and collaborative stakeholder workshops, the paper identifies and maps the **technical, regulatory, financial, and social barriers and drivers** affecting EPH implementation and demonstrates how the LEGOFIT digital platform can help overcome these challenges.

Sufficiency of methodological detail for replication – Partly
While the overall methodology is clearly outlined, the description of the **stakeholder workshops and qualitative analysis process** lacks sufficient detail to allow full replication. Key information such as the number and types of participants, workshop duration and structure, and the procedure used to synthesise and prioritise barriers and drivers is only briefly mentioned.
Required action:

- Provide more detailed information on the stakeholder workshops (e.g. participant profiles, number of attendees, format, duration).
- Clarify how qualitative data from the workshops were analysed, synthesised, and validated.

These additions are necessary to strengthen methodological transparency and scientific robustness.

Availability of source data for reproducibility – Partly
The authors have made a positive effort to ensure transparency by depositing underlying datasets in Zenodo. However, some figures derived from workshop outputs are currently unclear or illegible, limiting independent verification of the results.
Required action:

- Improve the clarity and resolution of figures presenting workshop outputs and ensure that all visualised data can be clearly interpreted.
- Explicitly link shared datasets to the figures and findings reported in the paper.

Points That Must Be Addressed to Ensure Scientific Soundness

1. Add missing references and correct minor typographical and layout issues.
2. Improve the clarity and legibility of figures presenting stakeholder workshop outputs.
3. Provide additional methodological detail on stakeholder workshops and qualitative analysis to improve transparency and replicability.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Artificial intelligence, circular economy, digital construction and Building Information Modelling.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 10 May 2025

https://doi.org/10.21956/openreseurope.20546.r53267

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Apostolos K. Vavouris

University of Strathclyde, Glasgow, Scotland, UK

An interesting manuscript discussing the findings from the LEGOFIT project, aiming in accelerating the deployment of Energy Positive Homes through a holistic platform that enables decision-making, designing, and knowledge exchange between the involved stakeholders. The methodology, with its 4 pillars described in the manuscript, addresses technical, regulatory, financial, and social barriers.
My comments to the authors:
I. Introduction, 1st paragraph: please provide a reference supporting the statement: "The European building stock is mostly outdated and energy-inefficient".
II. Introduction, 5th paragraph: There is a typo: "facingor" --> "facing or" (a space is missing).
III. Method: I would suggest including a schematic diagram that summarises the 4 methodological/theoretical pillars.
IV. Method, 5h paragraph: "This concept underlines the importance of a building's inherent bioclimatic performance, i.e., achieving high energy efficiency "without touching the button"—meaning without relying on mechanical systems." I would suggest expanding on that and include relevant literature on passive housing.
V. Table 1: RIBA column is justified to the left, whereas the other two columns are justified to the centre.
VI. Figures 8 and 9 that contain the barriers and drivers identified during the workshops are blurred and therefore illegible. Please update the two figures so that all source data are available, and consider including a summary of the key takeaway messages from these two figures.
VII. I would like to see some more information included regarding the collaborative workshop and its format, i.e., number of stakeholders / participants, length of the workshop, format etc.
VIII. There is some repetition of LEGOFIT features across different sections, I would suggest summarising LEGOFIT features and including them in a single section.
IX. The LEGOFIT framework is highly dependent on stakeholder engagement and regulatory support; during the collaborative workshops, have you identified limitations arising from these requirements? In discussion and conclusion sections, I would suggest expanding on the key limitations / blockers of the framework.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Electronic and Electrical Engineering, Positive Energy Districts/Neighbourhoods, Energy Monitoring, Energy Management & Conversion, Applied Energy Research, Renewable Energy Systems / Integration

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.