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Renovation process challenges and barriers: addressing the communication and coordination bottlenecks in the zero-energy building renovation workflow in European residential buildings

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ABSTRACT
The implementation of Nearly Zero-Energy Buildings (NZEB) renovation packages in Europe needs to be accelerated to meet the current decarbonization goals. To achieve this level of performance, building renovation strategies should shift towards solutions that incorporate a multitude of passive and active components, increasing the complexity and costs of the execution. Moreover, it requires the involvement of different stakeholders of the building supply-chain, resulting in additional difficulties in communication and coordination processes. To address this challenge, the present study aims at mapping the renovation process in digital platforms and addressing the respective bottlenecks. In terms of renovation process, several digital platforms were analysed to identify the type of information that the stakeholders require during the different renovation phases. By structuring the information along the renovation process phases, the different stakeholders can identify when the information can be provided and how the different type of information links to each other.

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KEYWORDS
Building renovation process; zero-energy buildings; building stakeholders; questionnaire; information flow; retrofitting; digital technology

1. Introduction

Accounting for almost 40% of energy consumption in the European Union (Tsemekidi-Tzeiranaki et al. 2020), the role of the existing building stock is instrumental in the energy transition and the goals for carbon neutrality of the built environment. More than 220 million building units, representing 85% of the EU's building stock, were built before 2001 and it is expected that 85-95% of the buildings that exist today will still be standing in 2050 (European Commission 2020). Moreover, the latest Energy Performance of Buildings Directive (EPBD) states that all existing buildings should be transformed into zero-emission buildings by 2050. Currently, almost 75% of the building stock is energy inefficient and only about 1% of the building stock is renovated each year (DIRECTIVE 2018/844/EU). Considering this point the European Commission launched its Renovation Wave in 2020. This strategy was introduced as a component of the European Green Deal, and includes an action plan that outlines specific regulatory, financial, and supportive actions to enhance building renovation (European Commission 2019, 2020). Its goal is to increase the rate of annual energy renovation of buildings by 2030 to at least twice its current rate and promote comprehensive renovation. Given the urgency of the situation, the EU must prioritize strategies to enhance the energy efficiency, reduce carbon emissions, and promote sustainability of buildings throughout their entire lifespan. Adopting circularity principles in building renovation can effectively lower the greenhouse gas emissions associated with building materials (DIRECTIVE P9_TA(2023)0068).

For this reason, the potential of the existing building stock to be renovated up to an energy-neutral quality is getting a lot of attention not only from policymakers, but also from social housing corporations and other institutional real estate owners, financial organizations, and end-users. To achieve this goal, it is crucial to improve the way we carry out building renovation (Jensen et al. 2018), increasing both the rate and depth of the renovation (Economidou et al. 2011; Artola et al. 2016).

Currently, the annual renovation rate of the building stock varies from 0.4 to 1.2% in the EU Member States (European Commission 2020), which is not on schedule to meet the emission targets (Broers et al. 2019) It needs to increase to around 2.5–3% of the housing stock per year to achieve policy goals (Sandberg et al. 2016; Wilson, Pettifor, and Chryssochoidis 2018). Furthermore, the majority of improvements in residential buildings consist of basic maintenance and shallow renovation; thus, broader or deeper energy renovation measures are required, shallow renovation consisting in the standard solution of thermal wall insulation and insulated glazed components is the one requiring lower initial costs but will never reach a return of investment in financial terms (Filippidou, Nieboer, and Visscher 2016; Semprini, Gulli, and Ferrante 2017).

Currently, digitalization provides new opportunities and facilitates the overall construction process by creating intangible

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assets that allows cheaper and faster design and production. While advances in computer-aided design (CAD) software and building information modelling (BIM) have progressively changed traditional design practices and communication methods (Wong, Ge, and He 2018), some studies have shown that the architecture, engineering and construction sector presents a slow rate of digitization, specifically in terms of building digital assets, expanding digital usage, and creating a highly digital workforce, as compared to many other manufacturing industries (Gandhi, Khanna, and Ramaswamy 2016; Manyika et al. 2015). This need for digitalization of the construction sector at a faster pace has been acknowledged by both researchers and practitioners (Lu et al. 2015; Rezgui and Zarli 2006). It is also important to mention that renovation, retrofitting, and refurbishment are important components of facility management, and currently, there is few research and implementation in this area, compared to the design and construction stages (McGraw Hill Construction 2014).

In fact, digital technologies aim to increase productivity; create opportunities for local firms to learn by customizing, adapting, and integrating global technologies; and provide powerful new tools for accelerating innovation processes (Sturgeon 2021). Therefore, with the increase of digitalization and the spread of digital tools and applications, the construction sector faces a need for digital platforms and hubs that should allow the development and generalization of common digital services and data for all stakeholders of the value chain, in all phases of construction processes (David et al. 2021; Turk, Giddey, and Klinc 2022).

Considering the building renovation process, several barriers and bottlenecks have been identified by different researchers and practitioners (Economidou et al. 2011; Meijer, Straub, and Mlecnik 2018; Jensen et al. 2013). Some researchers have categorized the barriers in five groups (Jensen et al. 2018; Meijer, Straub, and Mlecnik 2018): (1) Institutional and political barriers; (2) Market and economic barriers; (3) Financial barriers; (4) Technical barriers, and (5) Behavioural and social barriers. Other studies have shown that an important barrier also to consider is a lack of simple and holistic tools that can assist stakeholders in decision-making during the early stages of projects (Jensen et al. 2013).

Furthermore, energy efficient renovation decisions tend to be formally represented as being discrete financially-motivated events, subject to exogenous constraints or barriers (Wilson, Crane, and Chryssochoidis 2015). Financial considerations include upfront costs, costs of capital, future cost savings, and payback periods (Eyre and Rosenow 2012). Commonly cited barriers to cost-effective efficiency investments include a lack of available capital or access to capital, unreliable contractors, a perceived deficit of credible information on renovation measures and outcomes, and the inconvenience of renovating (Wang et al. 2015; Mahapatra et al. 2013). These barriers prevent otherwise positive beliefs and strong intentions towards energy efficiency from being realized (Skelton, Fernandez, and Fitzgibbons 2009; Wilson, Pettifor, and Chryssochoidis 2018).

Apart from financial, institutional and regulatory barriers, that determine the decision or willingness to renovate for building owners, there are also informational barriers, in terms of lack of common direction amongst the main stakeholders and lack of overview (Jensen et al. 2018). Information/knowledge, or lack thereof, is a well recognized barrier to energy-efficiency investments (Curtis, Mccoy, and Aravena 2018). The inertia of current supply-chain configuration and design practices, inadequate incentives, and lack of awareness hinder the market uptake of even the most cost-effective opportunities (Serrenho et al. 2019).

The role of the renovation supply-chain is then very important in addressing the barriers and improving implementation rates and depth. Particularly considering zero-energy renovation that needs to upgrade different components to achieve the desired improved performance, the integration of many components increases the complexity and the cost of those renovations. A most effective renovation process and communication between the supply (building industry) and the demand (building owners) can alleviate barriers related with lack of information and awareness, while reducing the time, effort, and costs.

Considering the renovation supply-chain perspective, this paper focuses on the analysis of the challenges and barriers that occur during the renovation process considering the information flow and process to facilitate and improve the overall renovation process. The main goal of this paper is to map the renovation process addressing its most important bottlenecks, to make the renovation process more efficient. The study builds on previous experiences on research projects (European Commission 2021), which employ digital tools related to renovation practice. It focused on identifying relevant information and data that support the different phases of the renovation process to identify the type of information that the stakeholders require during the different renovation phases. This analysis aims to help structuring and improving the workflow between all the actors. In the next step, the findings of the analysis were used as base material for designing an experts' questionnaire, which had the dual purpose of validating these parameters while gathering relevant information about the renovation process in a systematic and organized manner.

2. Methodology

To identify the type of information that the stakeholders require during the different renovation phases and provide a framework to structure the workflow between all the actors involved during the renovation process, two main methodological steps were executed: (1) Exploration of the current renovation workflow, through the use digital platforms and technologies and (2) Development and analysis of questionnaires on experts' views about the renovation process. First, a general overview of the state-of-the-art regarding building retrofitting processes was developed, based on the analysis of different Research and Innovation (R&I) projects that use or develop digital tools for renovation. The list of projects was extracted from the portal of CORDIS (European-Commision 2021). Based on this exploration, an experts' questionnaire was developed to collect relevant information in a systematic and organized manner. The results of the analysis of the questionnaire are described in section 3, addressing the main topics of the study:

- Renovation process: phases and tasks
- Stakeholders per phase and their role
- Information flow
- Main perceived bottlenecks.

2.1. State of the art and analysis of current renovation workflow

As mentioned before, digital platforms and hubs are increasingly facilitating the construction and renovation process; therefore, the main purpose of the analysis of existing projects related with digital platforms that focused on renovation processes was to identify the renovation process workflow, target users, the required inputs that need to be considered for the development of common tasks throughout the process, and the main outputs to be expected. To that effect, a list of relevant Research and Innovation (R&I) projects was compiled with relevant European projects found at CORDIS (European Commission 2021).

The analysis considered seventeen R&I projects that dealt with the development of digital platforms to support the renovation process. The assessment was aimed at identifying three main groups of parameters: (A) the target users for the different platforms, (B) the required inputs for the platform, and (C) the main outputs associated with different tasks conducted throughout the renovation process. Thus, the main result of the analysis of existing digital platforms was the generation of comprehensive lists of categories for those three types of information (Table 1).

2.2. Questionnaire

The questionnaire was developed with Microsoft Teams platform and consisted of 55 questions, including multiple-choice and open-ended questions, and it was structured in three sections: (1) General information about the respondents and the organization they represent; (2) General experience about the building renovation process; and (3) Specific experience: involvement in the different renovation phases. All the respondents had to give their informed consent at the beginning of the questionnaire, with all responses being anonymized prior to their assessment. The data was downloaded for analysis as an Excel workbook file, and it was analysed with content analysis and frequency techniques (Hsieh and Shannon 2005).

2.3. Qualitative analysis of open-ended questions

The open answers obtained by the sample were then assessed through content analysis techniques (Hsieh and Shannon 2005), to identify the main types of bottlenecks discussed by the experts. To execute this content analysis assessment the test of the open questions was coded or broken down, into manageable code categories (bottlenecks) for analysis (Hsieh and Shannon 2005) (See Appendix B). This process was conducted by manually coding the responses via inductive or open coding, that is, the identification of categories based on the in-depth exploration of the qualitative data itself, without the use of predefined codes. This followed an iterative process of coding and re-assessing the information, which ended in a list of categories, which defines the main types of bottlenecks identified throughout the renovation process by the sample.

2.4. Questionnaire sample

Forty-two complete questionnaires were gathered after the campaign was over, considering different types of stakeholders. Figure 1 presents the location of the forty-respondents and Figure 2 presents the number of respondents distributed according to the declared core business of their organizations. At first glance, it is clearly seen that some stakeholders are underrepresented, namely architectural designers, building managers, real estate developers, and governmental parties. The balance of the sample improves when clustering the stakeholders into teams (client, construction, design, and energy, as shown in Figure 3); nonetheless, the client team remains underrepresented in the responses, which needs to be considered when assessing the results.

Regarding the position of the respondents within the institutions they represent, most of them are middle managers ($n = 13$) and technicians ($n = 13$) (Figure 4); while the majority declared to have over 10 years of experience ($n = 16$), followed by people with between 5 and 10 years of professional experience ($n = 13$) (Figure 5).

3. Results

3.1. Renovation process: phases and tasks

To systematize and facilitate decision-making during the construction projects, different phases have been identified (Cooper et al. 2008; Klein 2013; RIBA 2020). The exact number of phases and subphases might vary in the different publications, but there is consensus on the main broad stages. These are (1) the pre-project, which defines the need for the project; (2) the pre-construction, when an appropriate design solution is developed; (3) the construction, which implements the solution; and (4) the post-construction, which aims at monitoring and maintenance of the project.

In renovations, which are still construction projects, the phases mentioned above also apply (Ferreira, Pinheiro, and De Brito 2013; Konstantinou 2014; Ma et al. 2012). However, since renovations deal with an existing building, the pre-project phase includes the analysis and diagnostics of the building to define the intervention's scope. Additionally, the current occupants, who might be there during construction, have a significant role in the execution phase, such as in the time planning. In the context of this study, the renovation phases have been defined as shown in Table 2. The questionnaire followed those phases and elaborated on the core tasks per phase.

3.2. Stakeholders and their role

Understanding the roles of the different actors involved in the implementation of renovation projects is paramount to facilitating the decision-making process, resulting in better solutions and improved cost and time efficiency.

Distinct roles throughout the process were identified considering the types of users targeted by the reviewed platforms, which are presented in Figure 5. Besides the definition of the user types to be potentially addressed, it is possible to see that most of the reviewed platforms targeted architects & engineering consultants, and building contractors, validating their central role within the decision-making behind any renovation process. Furthermore, the identification of the user types was complemented with a simplified understanding of the potential purpose they would seek by using such a platform. Thus,

Table 1. Overview of the analysed research projects (more details in Appendix A).

No.	Projects	Aim	Target
1	Hit2Gap	Data acquisition	Energy service companies, Building managers, Building engineering consultants
2	BIM4Ren	Digitization Renovation scenario modelling	Architectural Designers, Building engineering consultants, Building managers
3	Built2Spec	Quality check digital toolbox	Architectural Designers, Building engineering consultants, Construction companies
4	Energy Matching	Optimized Building energy with Skin solutions	Architectural Designers, Building engineering consultants, Construction companies, Energy service companies, Building managers, Real Estate developers / investors, Governmental bodies
5	BERTIM	High energy performance prefabricated modules with high energy efficiency An innovative holistic renovation process methodology Affordable business opportunity	Building managers, Construction companies
6	EUReCA	Evaluation of Urban Energy Demand at District level, energy conservation measures at district level	Architectural Designers
7	Creation of One Click LCA	Software and solutions in the construction, calculate environmental impacts * Faster eco-design, greener building	Construction companies, Architectural Designers, Building managers, Real Estate developers / investors, System supplier
8	StepUP	Renovation reliable Performance gap to $< 10\%$ and Time on site to $< 40\%$ Renovation investments	Building managers, Architectural Designers, Construction companies
9	NewTREND	Integrated Design Methodology Retrofit design towards the next generation of energy-efficient and sustainable buildings and districts	Architectural Designers Energy service companies
10	Retrokit	Increase efficiency and quality in home retrofit projects Reduce carbon footprint Improve well-being of their tenants	Building managers, Energy service companies, Construction companies
11	BRESAER	Technological combinations and energy saving estimates System potential by geolocation Support of envelope components installation Full monitoring and control system	Architectural Designers, System supplier, Construction companies
12	Zero-Plus	Housing that achieves renewable energy and energy savings targets; Clear information on cost and performance; Ensure information for optimal, cost-effective maintenance.	Architectural Designers, Building engineering consultants, Construction companies, Engineering consultants
13	HEAT4COOL	Retrofitting design planner tool Integration of Heating and Cooling solution Wastewater heat recovery Self-Correcting Intelligent Building Energy Management System (SCI-BEMS) Market oriented heating and cooling solution	System supplier, Architectural Designers Building managers, Construction companies, Building engineering consultants
14	BASAJAUN	Rural development Sustainable wood construction Digitalization and innovation	Construction companies, Architectural Designers, System supplier
15	SunHorizon	Analyse heat pumps and building integrated solar solution Cost reduction Increased lifetime and reduced maintenance Cover the whole H&C demand Demonstration to market, before the commercialization of the products	Architectural Designers, System supplier Building engineering consultants, Building managers, Energy service companies
16	RenoZEB	Fast retrofitting methodologies ICT Tools support Cost-effective and non-intrusive prefabricated multi-functional modular 'plug and play' systems for the renovation of building Monitoring system Training and awareness of the value chain to boost the nZEB market	Architectural Designers, Building engineering consultants
17	BIPVBOOST	Automated BIPV manufacturing line development Digitalized process and energy management system Advanced standardization activities Massive implementation in the building skin	Architectural Designers, Construction companies, Building engineering consultants, System supplier

most platforms being developed to support building renovations seem to primarily serve as a design support tool for design professionals, a tool to limit risk for contractors, or to support an efficient operation over time for building managers.

Table 3 links the stakeholder types with the stakeholder groups, and therefore, their respective roles during the renovation. Thus, the stakeholders' overview has been used in the questionnaire to discuss the roles of the stakeholders. An indicative list of business and company types that correspond to those stakeholders is also presented in Table 3. The list is not intended to be extensive but to clarify the stakeholder types. It should also be considered that the type of businesses might

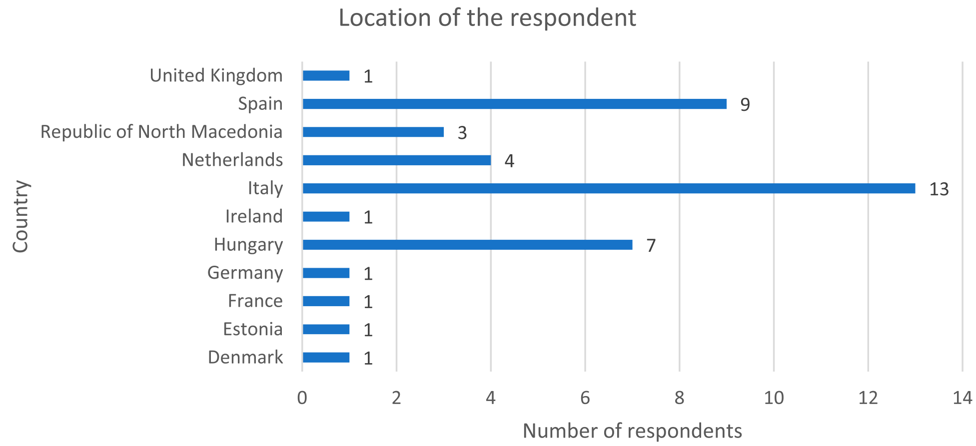

Figure 1. Location of the respondent.

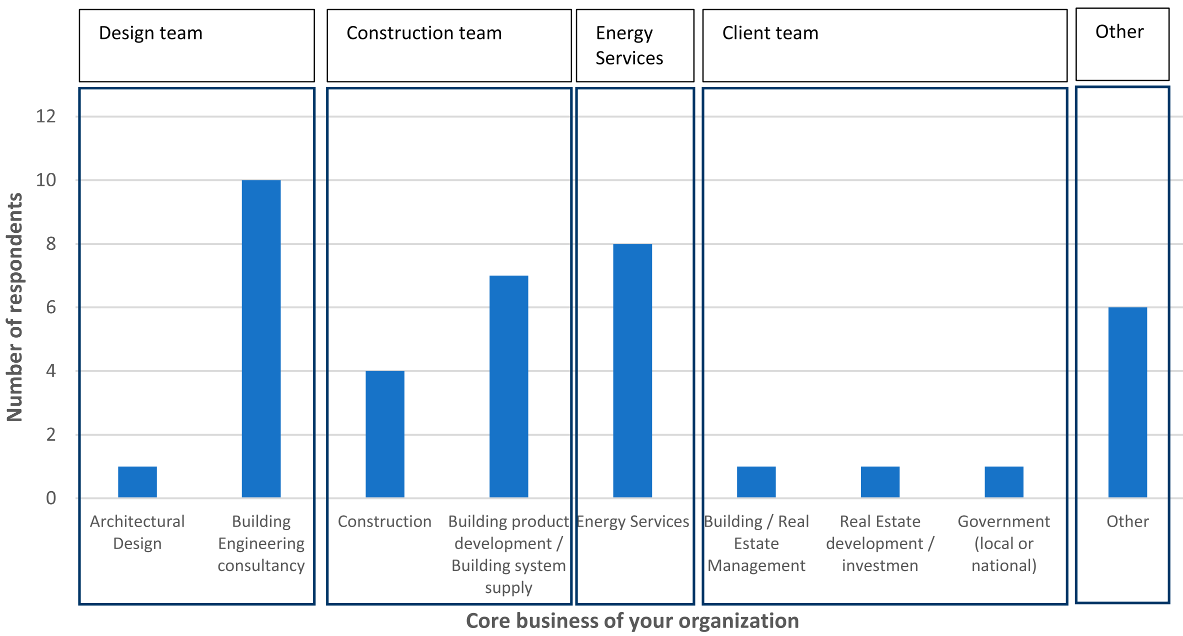

Figure 2. Core business of the organizations represented by the respondents (self-declared).

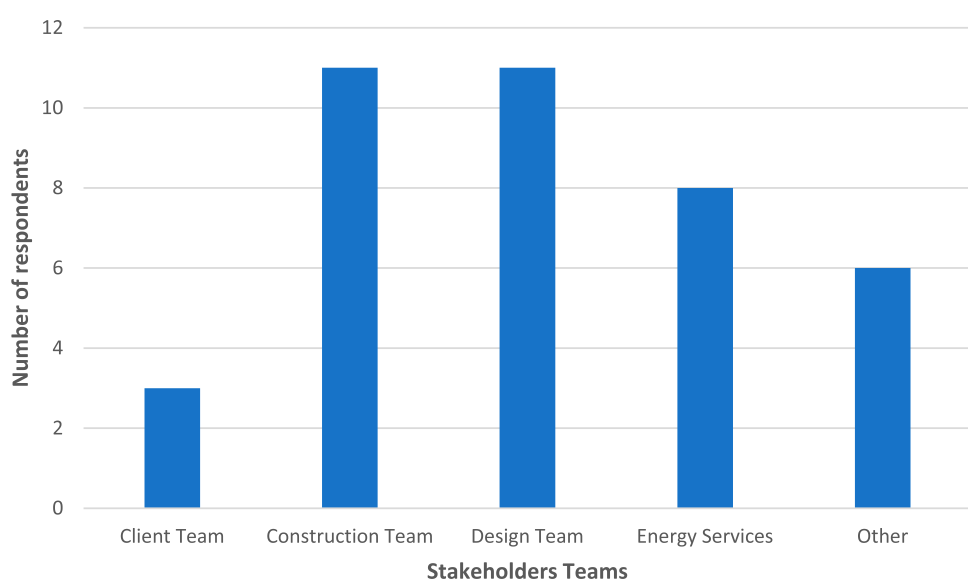

Figure 3. Organizations represented by the sample categorized in stakeholders' teams.

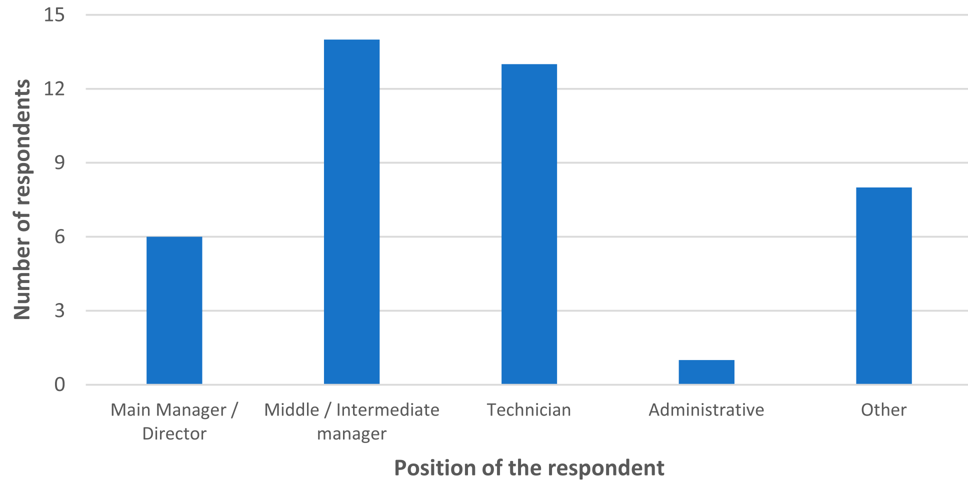

Figure 4. Position of each respondent within their organization.

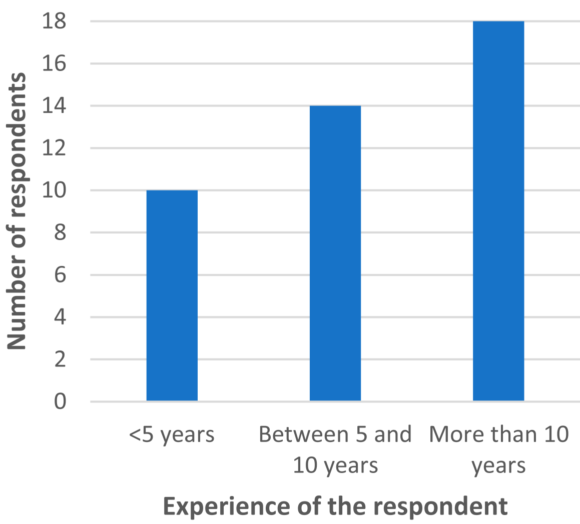

Figure 5. Declared experience of each respondent.

differ per country and project due to different supply-chain structures.

With the different stakeholders defined, the questionnaire asked the respondents to state which stakeholders are involved in each one of the renovation phases, and to discuss their perceived role throughout the process. The answers were organized for an easier appraisal of the results, defining three ranges based on the number of mentions: low, medium, and high perceived involvement. This resulted in the matrix shown in Figure 6, which considers the perceived involvement of the stakeholders for all phases, with different shades of blue signalling their involvement (darker shades mean higher involvement). The matrix clearly shows that the Design team (architects and engineering consultants) is perceived as being heavily involved throughout phases 1-4, and has a low perceived involvement in phase 5, which is particularly true for architectural designers. The construction team is perceived to be involved in phases 3 and

Table 2. Overview of renovation process phases and tasks.

Phase	1	2	3	4	5
Name	Pre-project	Concept design	Final design	Execution and handover	Post-construction
Description	Defines the need for the project, the problems, the ambition. Sets up the design team	Identification and comparison of strategy, interventions, design principles	Tender, specification of products, engineering of components	Manufacturing, assembly off-site and on site, hand-over	Post-occupancy evaluation / optimization loops
Core tasks included	Setting objective and criteria Diagnosis of existing condition Definition of client requirements Cost initial estimate Selection design team	Identification of renovation measures Decision on industrialized components design concept Assessment and optimization Preparation of permit applications	Detailed design for industrialized renovation Survey of existing building Engineering of the components Tender and products specification	Manufacturing Transport Mounting Site Construction Construction quality control Hand-over	Building operation optimization Monitoring Post occupancy
Phase outcome	Project Brief approved by the client, and confirmed feasibility	Renovation strategy approved by the client	All design information required to manufacture and construct the project completed	Manufacturing, construction, commissioning completed and hand-over	Building used, operated, and maintained efficiently.
Leading stakeholder	Client team	Design team Specialist consultants Client team	Design/construction team Specialist subcontractors	Construction team Specialist subcontractors	Client Facility management Specialist consultants

Table 3. Stakeholder's overview.

Stakeholder type	Stakeholder group	Business types
Architectural Designers	Design team	Planning and construction party; Urban planners; Architects
Building Engineering consultants	Design teamSpecialist consultants	Engineering consultants; MEP consultants; Sustainability consultants
Construction companies	Design teamConstruction team	General contractors; Subcontractors; Installers; One-stop-shops
System suppliers	Construction team	Suppliers of products or technologies; Suppliers of concepts or systems
Energy solution provider	Design teamConstruction team	Distribution system operator (DSO); Transmission system operator (TSO); Energy supply company; Energy service provider (ESCO); Renewable energy company; District heating/cooling network operator; Aggregator; Energy cooperatives /communities
Building owners	Client team	Private owner; Homeowner assembly; Housing cooperative or co-housing; Housing association or company; Private housing actor or real estate company; Public or social housing actor; Semi-public or mixed actor
Building managers/users	Client team	Facility management company; Building owner; Neighbourhood or residents' association
Real Estate developers / investors	Client team	Bank; Investment fund operator; Real estate development company; Project development company; Building portfolio manager
Policy actor	Client team	Municipality or city; County council; Provincial/ regional government. Federal/ national government body

4, especially during the latter (execution and handover). Energy solution providers are perceived to be involved throughout the process, from beginning to end; however, their involvement seems to peak during phases 3 and 4. Lastly, the stakeholders grouped in the client team are also perceived to be involved throughout the process, but especially in phase 1: pre-project, where the requirements and ambitions for the projects are set. Moreover, when it comes to phases 4 and 5, building users, managers and owners are understandably also heavily involved. This defines a sub-set within the client team, comprising stakeholders that mostly have a say in the beginning of the renovation process (developers, investors, government bodies) and others that will continuously deal with the building after the renovation (users, managers, and owners).

Table 4. Overview of inputs and outputs identified during the analysis of existing projects.

Input data identified	Output data identified
• Building description • Archetype buildings • Design scenarios • 2D plans • 3D models • Building services description • HVAC systems • Properties of the envelope • Materials • Monitoring data / Sensors • Energy consumption • Questionnaires • User schedules • Weather information • Location information • Cost of components • Performance of components • Pictures	• BIM models (existing and post-renovation) • Renovation scenarios comparisons • Installation's sizing • Maintenance data • Information for BEM system • Quality check reports • Indoor comfort information • Energy demands & consumption data • Energy production data / Self-sufficiency • Envelope retrofitting proposals / design options • Guidelines for logistics & planning • Cash-flow of the intervention • LCA & LCC results • GHG and CO_2 emissions

3.3. Information flow

The information flow between the stakeholders, consisting of input and output, is essential for the renovation process. The identified inputs and outputs considered in the data flows of the reviewed digital platforms are presented in Table 3. Regarding the inputs, most of them refer to information from the existing building, its envelope, and services. Additionally, other inputs refer to its occupation and operation, to information from the climate context, and cost data of building components and renovation activities. On the other hand, the main outputs along the renovation process refer to the generation of renovation scenarios and Building Information Models (BIM), energy flows data (consumption and generation), quality check and maintenance reports, Life Cycle Assessments (LCAs), and evaluations related to the cash-flow of the intervention (Table 4).

This list of inputs and outputs was included in the questionnaire, to ask the respondents to state the inputs they require to perform their tasks during each phase, and their main outputs along the process. The respondents were also given the possibility to add more options in case they felt the list was not comprehensive enough. Figure 7 and Figure 8 present the responses from the sample at each renovation phase, with colour codes based on the amount of mentions for an easier appraisal of the results. Figure 7 depicts the input types that are more commonly required by the sample of professionals, showing the relevance of counting with enough information about the building from the initial stages to construction. Cost information is particularly relevant as an input at the final design and construction phases, while operation inputs, although relevant throughout the whole process, are markedly more needed during phase 5.

Figure 8, follows the same pattern, showing the iterative process behind retrofitting design scenarios until the final design is set, and the use energy reports especially at the beginning and the end, to diagnose problems and later evaluate the solution, also considering comfort assessments. When it comes to the construction phase, the main declared outputs refer to guidelines for installation and assembly, logistics and planning, and budget estimations and cash-flow information.

3.4. Main perceived bottlenecks

The respondents were asked to mention the main bottlenecks they have perceived based on their own experience, which would need to be solved to increase the efficiency of the overall renovation process. This was conducted through a set of questions aimed at each phase separately, targeting the experts that had previously declared to have personal experience at each

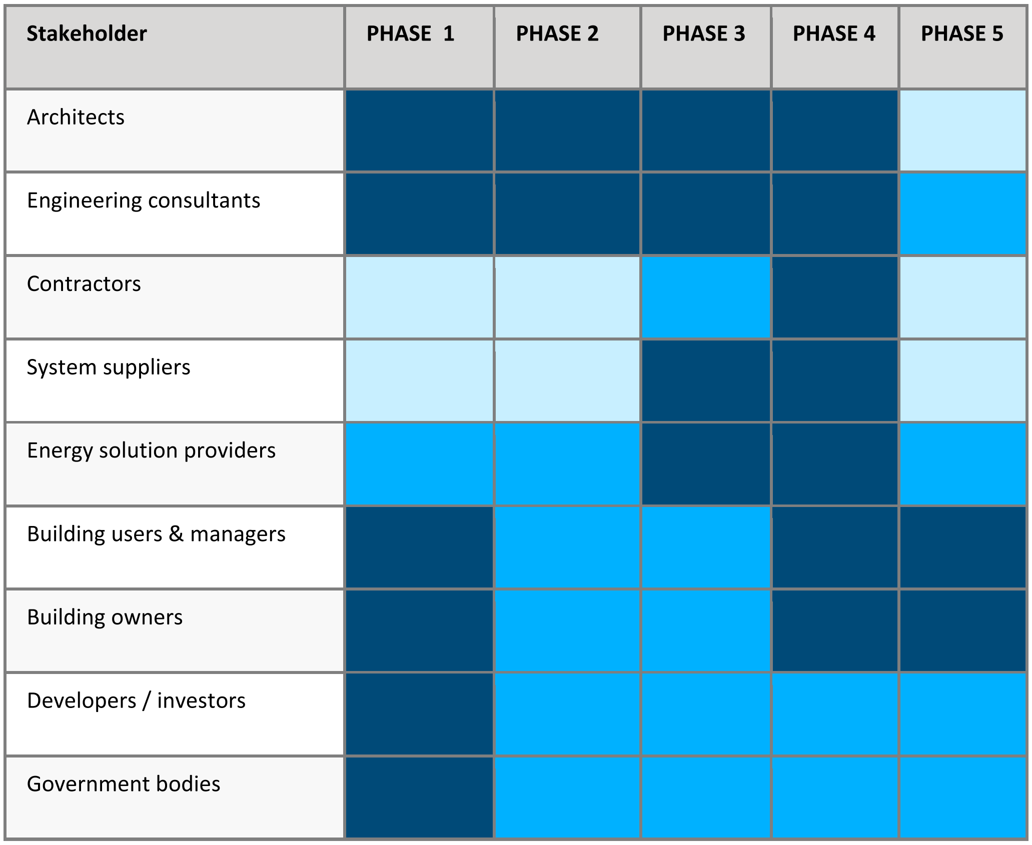

Figure 6. Stakeholders' involvement per phase categorized in ranges (low/medium/high perceived involvement, with darker colours signalling a higher perceived involvement within the renovation process).

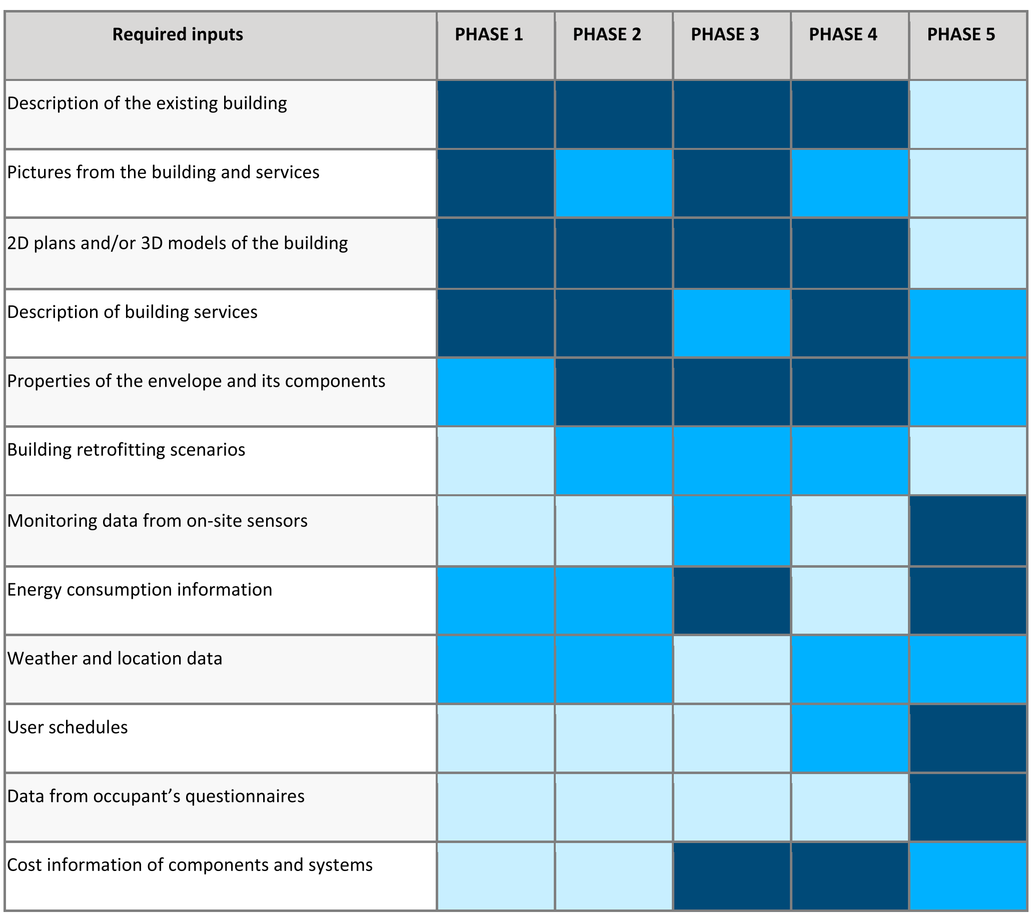

Figure 7. Overview of the main required INPUTS per phase according to the respondents' mentions. Low/medium/high relative mentions per phase are shown with colours (the darker the colour, the higher the number of mentions per phase).

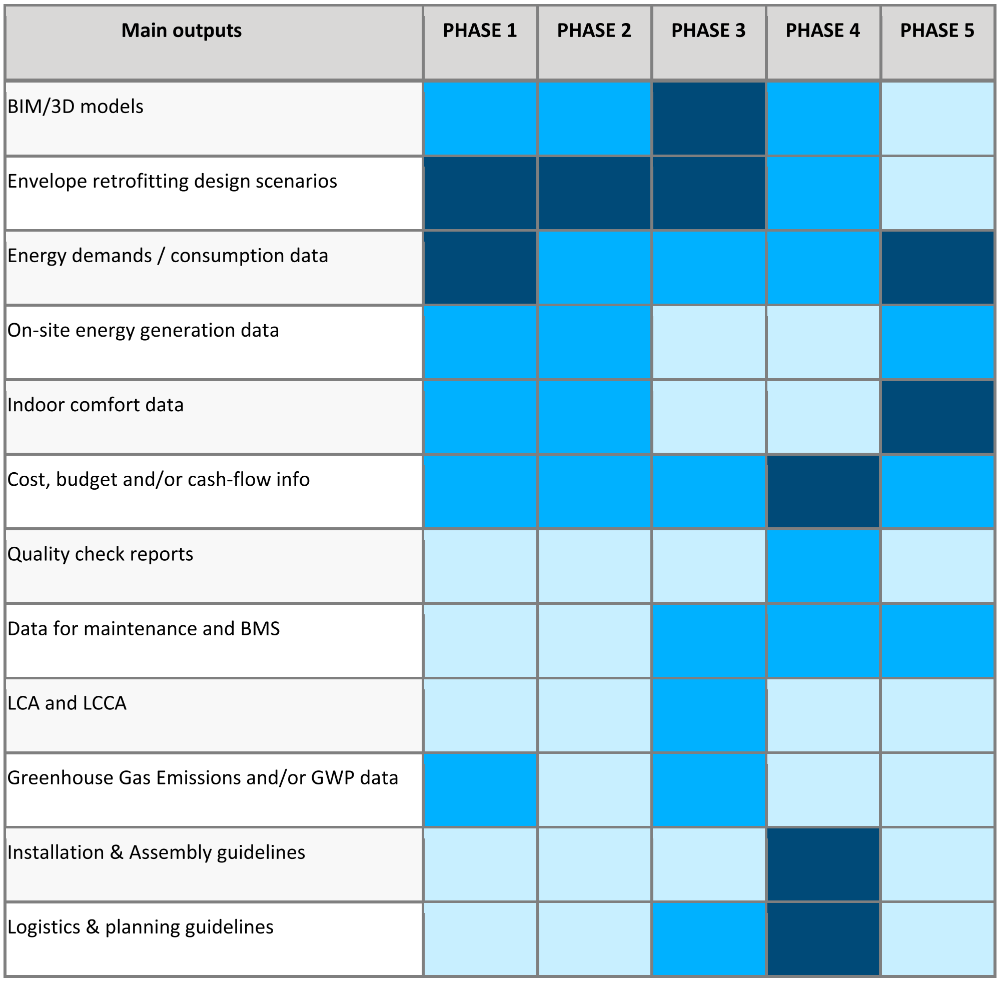

Figure 8. Overview of the main OUTPUTS per phase according to the respondents' mentions. Low/medium/high relative mentions per phase are shown with colours (the darker the colour, the higher the number of mentions per phase).

phase. These questions were open-ended, so the respondents were free to state the bottlenecks they perceive as important at each phase.

Seven main categories for the bottlenecks were identified, as follows: (1) Lack of information, (2) Unclear definitions, (3) Normative and Compliance, (4) Coordination and communication, (5) Responsibilities and guarantees, (6) Unreliable assessments, and (7) Technical challenges. Some outliers that did not respond to any defined category were grouped under an eighth one labelled 'others'. Table 5 provides the detailed bottlenecks identified for the respective category and renovation phase. A colour code in grey was used to identify the frequency of the answers given by the respondents where darker colours represent a higher amount of mentions per bottleneck type. Moreover, Appendix B presents the responses related with the identification of the bottlenecks per phase and how they were categorized based on the content analysis assessment described before.

The responses were then re-assessed and categorized based on the list of main types of bottlenecks, with the result being shown in Figure 9. There, it is possible to see that most of the mentioned bottlenecks clearly refer to lack of information, and coordination & communication issues, followed by normative and compliance aspects throughout the process.

The discussion about the renovation process workflow circled around the two main identified bottlenecks: (a) lack of information, and (b) coordination and communication. The responses from the experts' questionnaire showed that the former is the most recurrent bottleneck type during the first phases, which deal with the design of the renovation solution. However, at phase 4, when construction starts, coordination and communication issues are the most pressing matters to overcome to streamline the process and increase its efficiency.

4. Suggestions to overcome the bottlenecks

The analysis of the current renovation workflow, through the use digital platforms and technologies, and the questionnaire regarding bottlenecks and information flow during the renovation process provided a clear direction towards addressing and overcoming those bottlenecks (Table 2 and Figure 5). First, regarding the lack of information, it is important to establish clear responsibilities for gathering the information needed at each phase. To support this, a comprehensive building data checklist is necessary, considering the level of detail for said information at every step of the process. These strategies align with previous studies on renovation that discussed the importance of adequate information to match the purpose of

Table 5. Detailed overview of the identified bottlenecks per phase.

	PHASE 1	PHASE 2	PHASE 3	PHASE 4	PHASE 5
Lack of information	- Limited info about the existing building (construction, envelope, structure). - Limited energy consumption data		- Unclear design alternatives from suppliers. i.e. what colours, materials and shapes are possible. - Unclear detailed info on connections and installation materials.	- Not always enough technical information about the renovation components (façade panels)	- Post-occupancy evaluation is still rarely performed. - Limited access to monitoring data, which is usually fragmented. - Limited info on users' scheduled.
Unclear definitions	- Unclear definition of the renovation objective and KPIs. - Unclear design proposals at this stage hinder the clients' decision-making process.	–	- Unclear technical solutions and installation techniques for budget calculations and procurement.	–	–
Normative & compliance	- Bureaucracy	- Bureaucracy - Unclear overview of National or local normatives that need to be followed.	- Approval of the project by local authorities.	- Permits and green light from the local authorities and the client.	–
Coordination & communication	- Limited involvement and participation of specialists (mostly developer and owner).	- Communication issues and limited information exchange between stakeholders. - Unclear client-designer communication. - Low involvement and response time from system suppliers.	- Coordination issues and clear involvement among consortium members. - Lack of a central access point of information - Collaboration between different suppliers.		–
Responsibilites & guarantees	–	- Unclear responsibilities of the local architects and other stakeholders.	- Unclear responsibilities and liabilities at the procurement stage for quality checks, delivery, defects and replacements during and after construction.	- Unclear agreement of responsibilities between consortium partners.	–
Unreliable assessments	- Not enough depth in the technical project to come up with reliable cost estimations.	- Unreliable assessment and optimization of different design options. - Uncertain building energy performance predictions. - Unreliable cost predictions of energy services.	–	–	–
Technical challenges	–	–	- Integration and fine tunning of all the elements and components.	- Design and maintenance of the envelope. - Errors in accuracy might jeopardize the installation on-site. - Lack of standardization.	–
Others	- Lack of interested clients and governmental incentives.	- Lack of skilled professionals to assemble a consortium.	- Lack of skilled professionals to assemble a consortium.	–	- Lack of incentives for landlords in tenant-based scenarios.

an evolving renovation design process (Stegnar and Cerovšek 2019).

Moreover, next to identifying the need of information and its type, this study also highlights the importance for clarity regarding the information gathering process and responsibility. Even if responsibilities and data gathering activities are clearly defined, there is still a relevant information gap at the early-design stages, especially related to technical information that

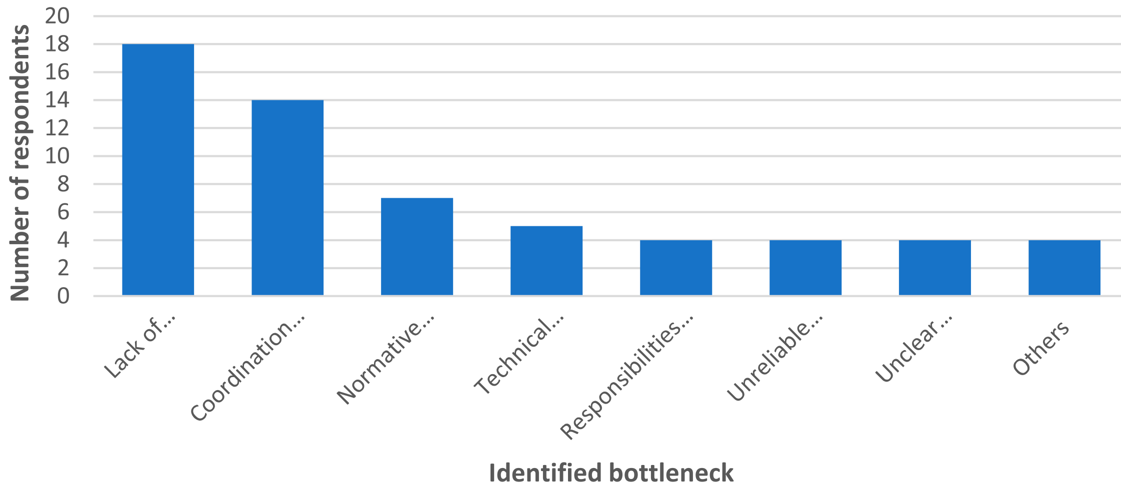

Figure 9. Main types of bottlenecks identified from the responses and the frequency of their mentions.

could otherwise serve as valuable input for the concept design. Furthermore, a building reference library would serve as a relevant complement in the early stages of the renovation process. This building reference library must include pre-defined building characteristics in different climate contexts to provide a quick referential framework for energy savings assessments and define feasible expectations during initial conversations with stakeholders from the client team.

Regarding coordination and communication issues, this study confirmed the barriers identified in the literature, such as lack of common direction amongst the main stakeholders and lack of overview (Jensen et al. 2018). The present study specified further as crucial to clearly define the responsibilities of all stakeholders throughout the process. Likewise, it was stated as central to have a clear definition of the requirements and key performance indicators which will be used to evaluate the project. Thus, it is paramount to consider clear communication channels between the design team and the client team from early on, with timely and comprehensive information. Therefore, a communication protocol must be designed and integrated during the whole renovation process to avoid and/or reduce miscommunication and to foster clear and direct information exchange among the stakeholders. This protocol could help reducing time throughout the process, besides supporting faster decisions in the face of changes and unforeseen events, especially during the execution phase (Table 2) where on-site events are bound to happen, and delays may have a sizable impact on the budget and on-site logistics. This communication protocol may result on a dedicated tool to house internal communications within the renovation team, where agreements can be reached, and information can be traced back to minimize risk and clearly establish responsibilities and guarantees throughout the process and it must include the checklist previously mentioned.

Finally, it was mentioned that the construction team (Figure 2) should be included in the process already in earlier phases, instead of waiting until the tender. This could potentially make the initial decision-making process faster and more grounded, by having technical opportunities and limitations clearly outlined when it comes to defining the main requirements and expectations.

5. Conclusions

The main goal of this study is to improve the renovation process workflow from the supply-chain perspective by analysing the renovation workflow in current digital tools, addressing its most important bottlenecks (Figure 5); therefore, the design team (Figure 2) can overcome in time these identified bottlenecks in every phase. Taking this into account, this study set off to investigate the building renovation process and its related bottlenecks, by looking at current practices and experts' experiences, with the main identified bottlenecks being the lack of information and coordination/communication issues (Figure 5). Even though the results in terms of the analysis of the bottlenecks were not surprising, this study specifies them in more detail, and it clarified the link between the bottlenecks and the different renovation phases (Table 2), so they can be specifically addressed during the renovation process. It is also important to mention that one limitation of this study is the sample size of the questionnaire, that's why the questionnaire was sent to individuals that are relevant to the field.

The result of the study concluded into key aspects and information that are needed during the renovation process, to overcome the identified bottlenecks. More specifically, the following key points were identified:

Stakeholders' involvement per phase (Figure 6):

- The Design team is heavily involved from the beginning to the handover of the project and the Construction team is present during mostly final design and execution.
- The Energy solution providers are seen involved throughout the process, but mostly during final design and execution.
- The Client team is involved throughout the process but mostly in the pre-project phase. During the execution and operation phases, the users, managers, and owners are also heavily involved.
- Main required inputs refer to information about the existing building, its services and its envelope, which is needed from the beginning to the handover of the project.
- The main outputs refer by the experts were the definition of envelope retrofitting scenarios during pre-project and design phases.

Main perceived bottlenecks per phase (Table 2)

- Lack of information seems to be the main perceived bottleneck during the pre-project and the concept design phases.
- Coordination and communication between different stakeholders are the main perceived bottlenecks at the execution and handover phases, along with technical challenges.
- Unreliable assessments were mentioned as a relevant bottleneck during the concept design as presented in detail in Table 5.

The recommendations regarding the type of information and processes that can facilitate the renovation and overcome the bottlenecks include the following:

- Pre-defined Building characteristics, to provide initial scenarios and an indication of cost and energy at the early stage, with minimum effort.
- Comprehensive building data checklist, considering the level of detail for said information at every step of the renovation process.
- Technical information on products, in form of a catalogue.
- The Construction team and the different suppliers should be involved earlier in the process.
- Clearly defined responsibilities of all stakeholders throughout the process
- Communication channels and protocols between the design team and the client team, for solutions approval and execution

By structuring the information along the renovation process phases, the different stakeholders can identify when the information can be provided and how the different types of information link to each other. The outcomes of the study can serve as the basis of a framework, providing stakeholders with a clear structure and access to a wide range of technologies from early decision making and data acquisition, to the manufacturing, construction works, and the operation and maintenance of the renovated building. Importantly, these results can be used in the development of communication protocols and tools to facilitate the renovation workflow, resulting in a more efficient renovation of the building stock.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request. The data that support the findings of this study are available upon reasonable request from the corresponding author. The data are not publicly available due to privacy restrictions. It contains information that could compromise the privacy of research participants.

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