ENSNARE - ENvelope meSh aNd digitAl framework for building Renovation

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Summary

The main goal of the ENSNARE project is to boost the implementation of NZEB renovation packages in Europe, with a focus on residential buildings. The project develops two key structures to accomplish this objective: an envelope mesh and a digital platform that interconnect all building components. The information in the present document relates to the definition and development of the Digital Platform, as part of the WP1 Platform for technology integration through industrialisation. The primary outcome of WP1 will be the development of a complete tool named "Digital Platform for envelope retrofitting" (DP4ER). The information included in this Deliverable 1.1 is the result of the works carried out in Task 1.1 ENSNARE DP4ER specifications, where the main objective is to define the characteristics of the digital framework that will be developed during the project.

The Platform's objective is to facilitate the exchange of information between the renovation actors to save time and costs. To this end, the ENSNARE DP4ER Specifications propose a digital framework which will be organised around three main axes: (1) Type of users and stakeholders; (2) Type of information that the platform should consider, including inputs and outputs; and (3) The renovation process, which includes time and information exchange method.

To define the Digital Platform's specifications, the consortium followed three main steps:

1. Exploration of current renovation workflow
2. Experts' interaction: questionnaire and workshop
3. Elaboration: DP4ER Modules and workflow

The present report describes the methods and results of the steps mentioned above, concluding with mapping the workflow of the Platform and the information modules that constitute the Platform's specifications.

Renovation workflow

The analysis of existing renovation practices started with identifying design patterns applicable in the renovation workflow and how the decision-making can be supported by building simulation software (Section 7). Subsequently, the analysis of different platforms that have been developed in previous projects (Section 8), and the definition of the renovation process, the phases it comprises, and the tasks that each phase includes (Section 9) set the basic structure of the specification and supported the development for the experts' questionnaire.

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After looking at design patterns for low-energy buildings, it can be concluded that the design decisions need to be supported by outputs tailored to provide information about the performance. Moreover, the dialogue between building designers, consultants, clients and other stakeholders; and knowledge transfer and resources on aspects of the low-energy building design is essential.

The analysis of R&I projects, compiled by previous projects where the consortium partners were involved, and complemented by relevant European projects found at CORDIS (European Commission, Cordis), identifies the type of input and outputs that provide the required information between the target stakeholders. Such data include, amongst others, building information, performance, and design scenarios.

The type of information evolves as the tasks develop through the renovation process phases, ranging from setting the project objective and building diagnostics in the pre-project phase to designing and optimising different renovation scenarios, execution, and post-occupancy evaluation. The stakeholder group that provides the input utilizes the output differs as well.

Experts' interaction

The results of the renovation workflow analysis were used as the basis for composing the expert questionnaire (Section 10), which aimed at gathering relevant information in a systematic and organised manner, from a sample of professionals from different fields with experience in renovation projects, organised in three sections: (I) General information about the respondents and the organisation they represent; (II) General experience about the building renovation process; and (III) Specific experience: involvement in the different renovation phases.

The primary outcomes of the questionnaire were about the main bottlenecks, the stakeholders' involvement, required inputs and outputs per phase.

Finally, to validate the outcomes and the findings from the literature review and from the experts' questionnaire, a workshop (Section 11) was executed where aspects related to the elaboration of the platform framework and workflow were discussed and analysed by the consortium members.

DP4ER Specifications

Based on the activities described above, we can conclude that the Digital Platform (DP4ER) should consist of different modules. Those modules are introduced in various stages but can also span over the phases. Most importantly, they can be used separately depending on the specific project's needs, but they also interlink

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to facilitate the exchange of information. Therefore, the following modules are defined as the Digital Platform's tools:

1. Reference module: provides energy and cost calculations from simplified building archetypes. Besides, this module should provide basic information to the client about regulations, standards, constraints, as well as a technical library (catalogue) of energy renovation solutions. It will allow the user to interact with the Early decision support Tool module as an interface between them.

2. Building data gathering module: collects and processes the necessary information of the building to design the prefabricated elements and devices, the required energy simulations, the off-site manufacturing, and the on-site installation.

3. Early Decision Support Tool module: proposes and assesses potential renovation solution kits.

4. BIM module: creates a model for the construction and technical specifications. It also stores semantic information that has been obtained either from the Early decision support tool or the Building data gathering module.

5. Coordination and communication module: establishes a digital communication protocol when the decision-making process is presented and approved by all the parties.

6. Digital twin module: creates a digital twin of the building, allowing for performance analysis, optimisation, and active control of systems during the operational phase.

The Digital Platform is aimed at providing stakeholders with a clear structure and access to a wide range of technologies for deep renovation of buildings. It supports all stages of the renovation process, from early decision making and data acquisition to the manufacturing, construction works, and the operation and maintenance of the implemented system. The Platform uses a digital toolbox (an open collection of modular tools) which is closely linked to a digital model of the building. As the process evolves, increases in complexity and interaction potentialities throughout the different renovation phases.

The Digital Platform specification developed in this deliverable 1.1 will not only be the starting point to develop the Platform (in WP1), but will also affect the development of the rest of the digital solutions (WP2, WP3 and WP4) as well as the physical components (WP5 and WP6).

List of Abbreviation

AIA	American Institute of Architects
BEM	Building Energy Models
BIM	Building Information Model
BMS	Building Management System
BPS	Building Performance Simulation
CAM	Computer-Aided Manufacturing
CO2	Carbon dioxide
D1.1	Deliverable 1.1
DAI	Design Analysis Interface
DP	Design Pattern
DP4ER	Digital Platform for Envelope Retrofitting
EDST	Early Decision Support Tool
ENSNARE	ENvelope meSh aNd digitAl framework for building Renovation
GHG	Greenhouse Gas
GWP	Global Warming Potential
H2020	Horizon 2020
HVAC	Heating, ventilation, and air conditioning
IEQ	Indoor Environmental Quality
IFE	Intelligent Front-End
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LOD	Level of Development/Detail
NZEB	Nearly Zero-Energy Buildings
PAM	Performance Assessment Methods
PV/T	Photovoltaic/Thermal
R&I	Research and Innovation
T1.1	Task 1.1
WP	Work Package

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1. Introduction

1.1. Context. ENSNARE project, WP1 and T1.1

ENSNARE (ENvelope meSh aNd digitAl framework for building Renovation) is a European funded research project under the H2020 Programme – Grant Agreement Number: 958445. The project will run between 2021 and 2025, by a Consortium comprised of 19 European partners from 12 countries.

The main goal of the ENSNARE project is to boost the implementation of Nearly Zero-Energy Buildings (NZEB) renovation packages in Europe, with a focus on residential buildings. To accomplish this objective, the project develops two key structures that interconnect all building components: an envelope mesh and a digital platform. The envelope mesh is fully modular and facilitates the mechanical assembly and interconnection of all components and energy/data networks. The Digital Platform is aimed at providing stakeholders with a clear structure and access to a wide range of technologies for deep renovation of buildings. It supports all stages of the renovation process, from early decision making and data acquisition to the manufacturing, construction works, and the operation and maintenance of the implemented system. The platform makes use of a digital toolbox (an open collection of modular tools) which is closely linked to a digital model of the building, which as the process evolves increases in complexity and interaction potentialities. In its final stage, the model is a Digital Twin that allows real-time control, simulation, and operation of all building components.

The information presented in this document is related to the definition and development of the Digital Platform, as part of the WP1 *Platform for technology integration through industrialization*. The objective of this first Work Package is to define the digital framework system that will be used to optimize the entire façade retrofitting works and to define the format to connect data and workflows between all the activities, with the aim of reducing time and cost of the entire process, considering the main phases and activities during renovation.

The main outcome of this WP1 will be the development of a complete tool, named as "Digital Platform for Envelope Retrofitting" (DP4ER). And for doing so, the process of definition requires to first, define the main expected specifications, then develop and materialise the solution, to conclude with a validation phase of the tool, using the real pilot buildings of the project as benchmark. The complete development of the platform will last until the end of the project in 2025.

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1.2. Purpose

The information included in this Deliverable 1.1 (D1.1) is the result of the works carried out in *Task 1.1 (T1.1) ENSNARE DP4ER specifications* where the main objective is to define the characteristics of the digital framework that will be developed during the project.

The information required to define these specifications is related with the required data describing the building to be retrofitted as well as with the technologies (physical and digital) that will be used to upgrade it. This implies systematising and standardising the process as much as possible, taking into account the main bottlenecks in the process, technical and legal requirements, cost, and time required for the different activities. The different perspectives of main stakeholders intervening in the renovation workflow is also crucial and a special attention will be paid to the different roles participating and also to the type and characteristic of information exchanged between them.

Thus, this initial activity is mainly focused on the identification of the main relevant information that is required to develop the process, involving the extraction, combination, and visualization of the data in the retrofitting process.

1.3. Relation with other activities

This deliverable collects the outputs from T1.1 and is regarded as the first step for the development of the DP4ER. The results will mostly feed into other activities and deliverables within WP1:

- **Task 1.2 ENSNARE DP4ER architectural software design** - *Digital model definition and workflow:* The main structure of the tool will be defined at this stage, specifying the type of data that is exchanged between the main components of the system.
- **Task 1.3 Implementation of the ENSNARE DP4ER backbone and visualization interface:** This task will effectively develop the platform, based on the architecture and specifications as defined in previous tasks.
- **Task 1.4 DP4ER LCA/LCC tool:** As part of the overall platform, a specific module for Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) tools will be produced.
- **Task 1.5. Validation of DP4ER in the ENSNARE pilots:** Once the complete platform is being developed, a validation phase will be carried out to confirm the performance of the platform against the expected specifications. Real and virtual pilot buildings of the project will be used for this purpose.

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Apart from the specific research aimed to materialize the platform in WP1, the works performed in these activities are also related with the rest of work packages inside ENSNARE, as the platform settles the overall framework.

The project pays special attention to the early-decision stage, where the clients are oriented and supported, suggesting the main advantages and benefits of using the technologies developed and promoted by ENSNARE: industrialization, modular envelope systems, integration of renewable energy harvesting systems and the use of tailored digital tools for the different phases of the renovation process. To do so, a bespoke *Early Decision Support Tool* (EDST) will be defined in WP3, as subcomponent of the platform, that will be used to obtain the data from the building in a first iteration maximizing the reduction of time and costs of the process and optimizing the information to be provided to the potential client.

At this stage, the collection of data from the building requires inputs from two levels: the first one using available online information to be able to give a fast and economic answer about the characteristics of the building and a potential renovation using ENSNARE's technologies, and a second iteration, improving the detail of the information once the decision to renovate has being taken. This double approach will be investigated in *WP2 Building Data acquisition modules*, improving the detail and the efficiency of the subsequent retrofitting process, and reducing the time and visits to the building that this type of work usually requires.

The final stage of the intervention will be a detailed representation of the building, already renovated, incorporating active components that can be monitored in real data based on an *Operational Digital Twin* that will be developed as part of WP4. In parallel, those components will be defined, manufactured, and tested as part of the research in WP5 *Industrialized and modular envelope system* and WP6 *Energy harvesting and storage modules*.

Once validated the main solutions developed in ENSNARE will be implemented in WP7 *Pilot buildings*, considering three real buildings and three virtual ones. The developments in the field of digital solutions (WP1-4) as well as physical solutions (WP5-6) will be analysed demonstrated, at this stage, the behaviours of these in a real building scenario.

For properly orienting all those activities and WPs, the specifications identified and considered in this initial stage in T1.1, are necessary and relevant to define the specifications of all these components before starting to develop them.

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2. Method

To develop the specification of the Digital Platform, the following steps were followed:

1. Exploration of the current renovation workflow

2. Experts' interaction: questionnaire and workshop

3. Elaboration: DP4ER Modules and workflow

Figure 6.1 indicates the general scheme of the methodological structure used to define the approach and scope of the Digital Platform and to outline the ENSNARE DP4ER Specifications. First of all, a general overview of the current literature review and data available regarding façade retrofitting processes was developed, including the information and analysis of Design patterns (Section 3), Existing platforms (Section 4) and Renovation processes (Section 5). Based on this exploration, an experts' questionnaire (Section 6) was developed to collect relevant information in a systematic and organised approach. Finally, to validate the outcomes and the findings from the literature review and from the experts' questionnaire a workshop (Section 7) was executed where aspects related with the elaboration of the platform framework and workflow were discussed and analysed by the members of the consortium.

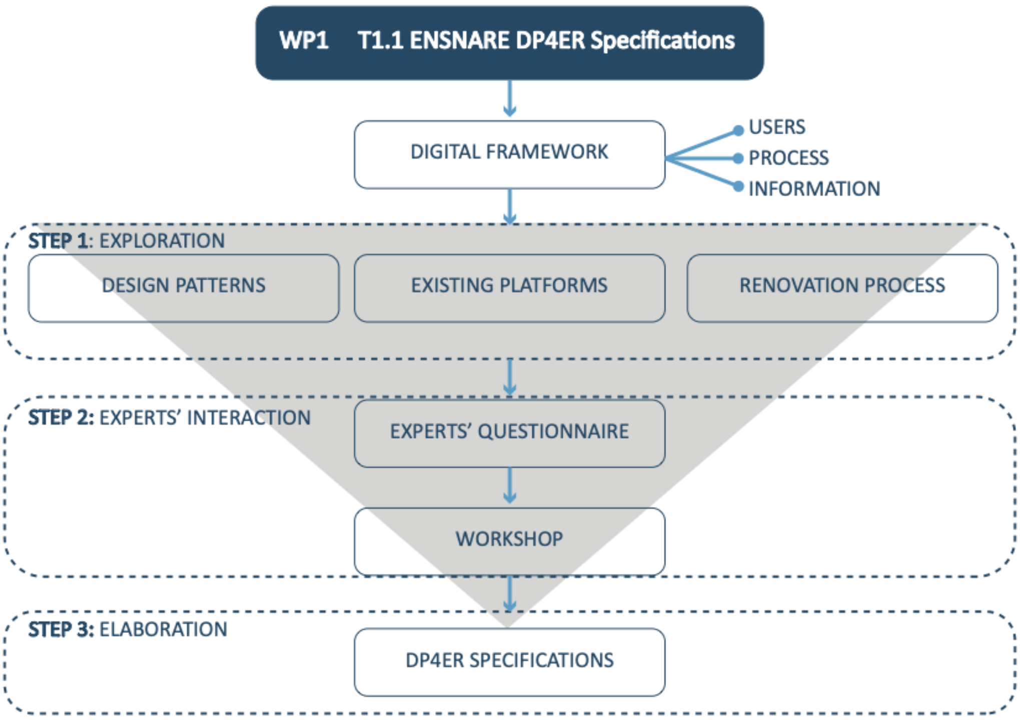

Figure 2.1. DP4ER Specification methodological structure scheme

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Scope

The aim of the ENSNARE project is to develop a digital platform to display and encourage the application of NZEB renovation packages in Europe focussing mainly on residential buildings. This Digital Platform will help the stakeholders throughout the whole renovation process by providing different kinds of technologies and strategies based on the needs of every renovation project. Taking this into account a digital framework was developed to define the ENSNARE DP4ER Specifications. This digital framework in presented in Figure 6.2, and it is organised around three main axes:

1. **Type of user:** Identifying who is the main user of the platform and how is the interaction between the stakeholders.

2. **Type of information:** Identifying what kind of information is needed in every phase regarding the needs of every stakeholder, including the characteristics of the inputs and outputs of the platform.

3. **Type of process:** Identifying the specific methods, strategies and/ or technologies for every renovation project, including time planning overviews.

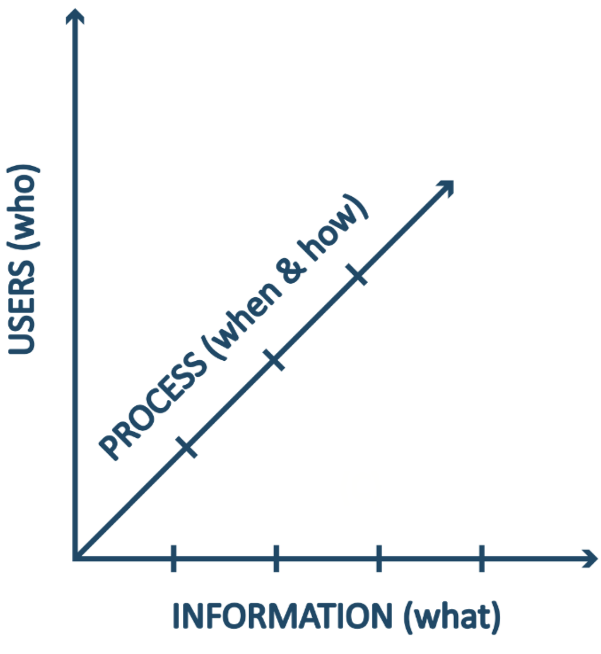

Figure 2.2. Digital Platform framework axes: who should communicate with whom, when, how and about what?

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3. Design patterns (DPs)

This section summarizes how the DP concept can help to develop the DP4ER Specifications and framework. First, a general overview of the DP concept is described to establish which strategies can be used in the execution of the DP4ER framework. A pattern language explains that each pattern describes a problem that occurs repeatedly in our environment, and then describes the core of the solution to that problem, in a way that the costumer uses this solution a million times over, without ever doing it the same way twice (Alexander, 1999). Design patterns are a universal resource to align best practices, describe the elements of good designs, and most importantly, provide a repository so that other people can easily reuse these solutions. Thus, it is a formal way of documenting solutions to common design problems.

The pattern concept is primarily a set of design guidelines, but also, it enforces some ordering constraints to complement the design. This concept is built as a network that includes the context, the (digital) language, complete designs, and detailed steps of intervention (Alexander, 1999). In addition, researchers have noted the need for better uptake of simulation tools in practice to provide design-related information (Bleil de Souza & Tucker, 2015). This problem is often attributed to a lack of integration of simulation tools into the 'design process' and/or the difficulties involved in the construction of virtual models (Fowler & Rose, 2004). The current information available for a building performance tool is given as handbooks, generic instructions and is expected to be acquired through practice.

While this knowledge is more concerned with qualitative and physical abstract solutions for abstract building design problems rather than with procedures and protocols, patterns have subsequently been found useful in the field of software engineering where they are used to store procedures (i.e., code) (Kuikka, 1999). Patterns have also been used successfully in the fields of interaction design (Fischer, 1993) and human–computer interaction (Tidwell, 2011) which are concerned with enabling human users to interact productively with computers and with other digital artefacts.

3.1. Design decision-making practice in previous simulation tools in Building performance simulation (BPS).

The main goal of Building performance simulations (BPS) is the quantification of properties of building performance related with the design, construction,

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operation, and control of buildings, including outputs on low-energy and low-carbon performance. However, several initiatives and tools used in BPS have failed because of their focus on development of just one specific tool (De Wilde and Van de Voorden, 2004). In fact, the approach of existing tools considers fixed interaction modes and dialogues for the required design process producing data-outputs based on the design team's point of view. Subsequently, several researchers have suggested different approaches to increase the potential of BPS, described as it follows (Tucker & Bleil de Souza, 2016):

- Development of user-friendly interfaces to BPS engines such as Design Builder, Open Studio.
- Design advice systems, where BPS can be used to provide performance information (Soebarto & Williamson, 1999).
- Generation of design alternatives, or generation of 'design space' to act within (Marsh and Hagperast, 2004).
- Systems that support dialogue between expert simulation users and the design team (Augenbroe et al. 2004).
- Systems that focus on supporting design processes and/or data management to provide better integration of existing tools into design processes (Mahdavi, 2004)
- The intelligent front-end (IFE) system: modelling decisions based on simulations.
- Performance assessment methods (PAM): were intended to define simulation procedures to determine the multivariate performance of a building model, and linked simulation actions (e.g., calibrate, simulate, identify problem areas, analyse results, postulate remedies, and iterate) to knowledge (e.g., of reliable techniques, suitable criteria, appropriate design options and justifiable level of resolution) (Clark et al., 1996).
- Design Analysis Interface (DAI) Initiative 'analysis functions': identify and define a virtual experiment to be carried out on the model in addition to defining a data model and aggregating output data (Augenbroe et al., 2004).

3.2. Outline Patterns Structure

Outline patterns focus on connecting design aims with simulation outputs that are tailored to respond to these aims (Tucker et al., 2016). It specifies the details of the required models, the simulations to be run, analytical processes and any postprocessing of results. The **Model settings** section includes details of model parameters such as climate files, time periods for the simulations and levels of modelling resolution required. **Analytical processes** are the different types of analysis that can be undertaken to address the designer's goals and include

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(Tucker & Bleil de Souza, 2016): Description of the results; a comparison of the effects on performance of two or more design actions or design alternatives; sensitivity tests; elimination parametric tests; and optimisation routines. Those parameters can be varied either singly or in combination (Macdonald, 2002). Overall, the **simulation outputs** provide information on performance metrics, different types of suitable display systems, analytical processes used to generate the requested information, and/or different types of data interaction afforded by the represented system (Table 3.1).

Table 3.1 Structure of data interaction (Shneiderman, 1996)

Overview	It gives the user a broader picture of a phenomenon
Zoom/filter	It allows the user to focus on an area of specific interest
Details on demand	It requires the user to actively ask for a specific type of detailed information
History	It allows the user to retrace steps
Relate	It enables the user to compare

Each specific aim can be connected to a specific type of analysis process, set of metrics and number of displays.

The designer's aims are represented by questions from which model settings and analytical processes can be specified to produce information to allow the aims to be met. Each question has two parts:

- A standard part which refers directly to the aim, and which allows an analytical process needed to meet the aim to be specified.
- A custom part where the user defines which design actions or changes associated with a design parameter are to be investigated.

3.3. Design patterns in the context of DP4ER framework

The aim of the exploration on the use of patterns was to inform the construction of a BPS knowledge management scheme to aid design the decision-making in the support design of low-energy buildings. The design of low-energy buildings using BPS consists of solving problems of:

- Presentation of relevant and appropriate information to support the design team in making design decisions.
- Building design and its relation to low-energy performance.

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The recurrence of these problems has a parallel in the recurrence of design problems in the fields of architectural design, software engineering, interaction design and education. The uses that those patterns have found in these fields suggest that they may be of use in the structuring of simulation processes and outputs to support decision-making for low-energy building design.

The potential uses of DP in the elaboration of the ENSNARE DP4ER Specifications is described as it follows:

- To provide support for design decisions by linking questions about the performance of a building to analytical procedures and outputs tailored to provide answers to these questions.
- To give non-expert users such as building designers access to the potential uses of BPS in design decision-making.
- To increase and enable dialogue between building designers, consultants, clients, and other stakeholders using patterns that represent expert knowledge and through which knowledge can be transferred.
- To support automatic routines for quality assurance and sophisticated analytical processes such as optimisation and parametric tests.
- To provide a repository of knowledge and an educational resource on many aspects of low-energy building design and on productive use of BPS.

Understanding how certain DP have been integrated in the workflows of existing platforms will help to understand how the inputs interact with the overall information flow and generate the desired outputs in other BPS endeavours, which could be applicable in the development of the DP4ER framework. Therefore, to identify the potential applications of DP in BPS, and to connect the outputs with the inputs and the information flow within BPS knowledge management schemes, an analysis of similar existing digital platforms is presented in the next section.

4. Analysis of existing platforms

T1.1 considered a series of activities to comprehensively define the DP4ER specifications. After the initial definition of the approach and scope of the platform, the first step was to analyse previous research experiences on the development of digital platforms that identify relevant information and preliminary data to be considered throughout the process. A list of relevant R&I projects was compiled to that effect, starting with previous projects where the consortium partners were involved, which were then complemented by relevant European projects found at CORDIS (European Commission, Cordis).

The list of reviewed experiences added up to 17 R&I (Research and Innovation) projects, shown in table 4.1, with some basic information. Their assessment was aimed at identifying three main groups of parameters, to be used as founding information for DP4ER: (i) target users for the different platforms, (ii) required inputs, and (iii) main outputs associated with different tasks conducted throughout the renovation process. Thus, the main result of the analysis of existing platforms was the generation of comprehensive lists of categories for those three types of information. These lists were then used to drive discussions within the consortium members, aimed at further defining the scope, ambitions, goals and limitations of the DP4ER. Furthermore, these lists were used as base material for the experts' questionnaire carried out as part of T1.1 with the dual purpose of validating these preliminary findings while gathering relevant information about the renovation process in a systematic and organized manner.

Table 4.1. Overview of existing platforms (APPENDIX 1: presents a complete overview of the analysis)

No.	Name	Aim	Duration*	Description	Link
1	**Hit2Gap**	Data acquisition	2015-2019	The HIT2GAP project developed a new generation of building monitoring and control tools based on advanced data treatment techniques allowing innovative approaches to assess building energy performance data, getting a better understanding of building's behaviour and hence a better performance.	https://hit2gap.eu https://bemserver.com
2	**BIM4Ren**	Digitalization	2018-2022	BIM4REN starts from 3 workflows adapted to the construction sector segmentation presenting	https://bim4ren.eu

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		Renovation scenario modelling		technical and organisational requirements and has adapted the project and consortium to provide adequate and innovative processes, methodologies, software, and hardware tools & BIM developments	
3	**Built2Spec**	Quality check digital toolbox	2015-2018	Built2Spec brings together a new and breakthrough set of technological advances for self-inspection and quality assurance that will be placed in the hands of construction stakeholders to support compliance with EU energy efficiency targets, new building standards, and related EU policy ambitions within the built environment.	http://built2spec.eu
4	**Energy Matching**	Optimised Building energy with Skin solutions	2017-2022	EnergyMatching aims at developing adaptive and adaptable envelope and building solutions for maximizing RES (Renewable Energy Sources) harvesting.	https://platform.energymatching.eu/ https://www.energymatching.eu/ https://cordis.europa.eu/project/id/768766
5	**BERTIM**	High energy performance prefabricated modules An innovative holistic renovation process methodology Affordable business opportunity	2015-2019	BERTIM aims to provide (1) high energy performance prefabricated modules for deep renovation, integrating windows, insulation materials, collective HVAC systems, renewable energy systems and energy supply systems; (2) an innovative holistic renovation process methodology based on a digital workflow from design to installation phase; and (3) affordable business opportunities for different stakeholders as potential leaders in the launching of the renovation process.	http://bertim.eu/index.php?lang=en

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6	**EUReCA platform: Energy Urban Resistance Capacitance Approach**	Evaluation of Urban Energy Demand at District level Evaluation of energy conservation measures at district level		EUReCA provides an efficient and reliable Urban Building Energy Modeling platform, entirely developed in Python, aiming at simulating, and predicting cities and urban areas energy consumption. The tool exploits a bottom-up modeling methodology, creating simple and useful dynamic building energy models.	https://github.com/BETALAB-team/EUReCA https://research.dii.unipd.it/betalab/facilities-tools/simulation-models/ https://www.sciencedirect.com/science/article/pii/S0960148121005085
7	**Creation of One Click LCA Platform for calculating life cycle emissions - Global market leader in building LCA**	Life cycle assessment and life cycle costing. Tools for LCA calculations and company GHG-reporting.	2016-2018	One Click LCA is a construction-sector life-cycle metrics platform which uses automation and user-friendly interfaces to make life-cycle assessment (LCA) and life-cycle costing (LCC) more accessible for non-specialists, with the aim of increasing their usage to drive down construction sector environmental impacts	www.oneclicklca.com https://cordis.europa.eu/project/id/711303
8	**StepUP** **Solutions and Technologies for deep Energy renovation Processes UPtake**	Renovation reliable Performance gap to <10% Time on site to <40% Renovation investments	2019-2023	StepUP project will develop a new deep renovation methodology, based on understanding both building performance and impact of the interventions through building data and physics-based modelling.	https://www.stepup-project.eu/
9	**NewTREND**	Integrated Design Methodology Retrofit design towards the next generation of energy-efficient and sustainable buildings and districts	2015-2018	NewTREND seeks to improve the energy efficiency of the existing European building stock and to improve the current renovation rate by developing a new participatory integrated design methodology targeted to the energy retrofit of buildings and neighbourhoods, establishing energy performance as a key component of refurbishments.	http://newtrend-project.eu/
10	**Retrokit**	Increase efficiency and quality in	2012-2016	RetroKit developed multifunctional, modular, low cost and easy to install	https://retrokit.eu/

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		home retrofit projects Reduce carbon footprint Improve well-being of their tenants		prefabricated modules, integrating efficient energy use systems and RES for systemic retrofitting of residential buildings.	
11	**BRESAER**	Technological combinations and energy saving estimates System potential by geolocation Support of envelope components installation Full monitoring and control system in charge of gathering data from the sensoring network	2015-2019	The overall objective of BRESAER project is to design, develop and demonstrate an innovative, cost-effective, adaptable, and industrialized envelope system for buildings refurbishment including combined active and passive prefabricated solutions integrated in a versatile lightweight structural mesh.	http://www.bresaer.eu/
12	**Zero-Plus**	Energy and energy savings targets set by the recipient at the lowest possible costs Clear information on the trade-offs between cost and performance Ensure that the recipient has all the information they need for optimal, cost-	2015-2020	In ZERO-PLUS, a comprehensive, cost-effective system for Net Zero Energy (NZE) settlements is developed and implemented. The system is composed of innovative solutions for the building envelope, for building energy generation and management, and for energy management at the settlement level.	http://www.zeroplus.org/index.php

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		effective maintenance.			
13	**HEAT4COOL**	Building retrofitting Retrofitting design planner tool Integration of Heating and Cooling solution Wastewater heat recovery Self-Correcting Intelligent Building Energy Management System (SCI-BEMS) Demonstrate and validate the market-oriented heating and cooling solution	2016-2021	Heat4Cool proposes an innovative, efficient, and cost-effective solution to optimize the integration of a set of rehabilitation systems to meet the net-zero energy standards. The project develops, integrates, and demonstrates an easy to install and highly energy efficient solution for building retrofitting that begins from the Heat4Cool advanced decision-making tool	https://www.heat4cool.eu/
14	**BASAJAUN**	Rural development Sustainable wood construction Digitalization and innovation	2019-2023	The project will focus on optimal utilisation of wood forest resources for the construction of a four-storey apartment building. The project will also undertake the digitalisation of the construction value chain, from forest to buildings.	https://basajaun-horizon.eu/#basajaun
15	**SunHorizon**	Analyse heat pumps and building integrated solar solution Cost reduction Increased lifetime and	2018-2022	SunHorizon will demonstrate up to TRL 7 innovative and reliable Heat Pump solutions (thermal compression, adsorption, reversible) that acting properly coupled and managed with advanced solar panels (PV, Hybrid, thermal) can provide heating and cooling to residential and tertiary building with lower	https://www.sunhorizon-project.eu/

		reduced maintenance Cover the whole H&C demand Demonstration to market, before the commercialization of the products		emissions, energy bills and fossil fuel dependency.	
16	**RenoZEB**	Fast retrofitting methodos 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	2017-2021	RenoZEB aims to unlock the nZEB renovation market leveraging the gain on property value through a new systemic approach to retrofitting that includes innovative components, processes, and decision-making methodologies to guide all value-chain actors in the nZEB building renovation process, including integrated solutions with highest impact in the revalorization of the building.	https://renozeb.eu/
17	**BIPVBOOST**	Automated BIPV manufacturing line development Digitalized process and energy management system	2018-2022	The main objective of BIPVBOOST project is to bring down the cost of multifunctional building-integrated photovoltaic (BIPV) systems, limiting the over-cost with respect to traditional, non-PV, construction solutions and non-integrated PV modules, through an effective implementation of short and	https://bipvboost.eu/

		Advanced standardization activities Massive implementation in the building skin		medium-term cost reduction roadmaps addressing the whole BIPV value chain and demonstration of the contribution of the technology towards mass realization of nearly Zero Energy Buildings.	

*Duration refers to the European Funding period

4.1. Main outcomes of the analysis

As it was mentioned before, the main purpose of the analysis of existing platforms was to identify a comprehensive set of categories to drive the initial development of the DP4ER, in terms of potential target users of the platform, the required inputs that need to be considered for the development of common tasks throughout the process, and the main outputs to be expected from these. Regarding the types of users targeted by the reviewed platforms, figure 4.1 shows the identified categories on the left, with the research projects on the right. 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, it mostly serves as a design support tool for design professionals, a tool to limit risk for contractors, or to support efficient operation over time for building managers. This is highlighted below each user type in figure 4.1.

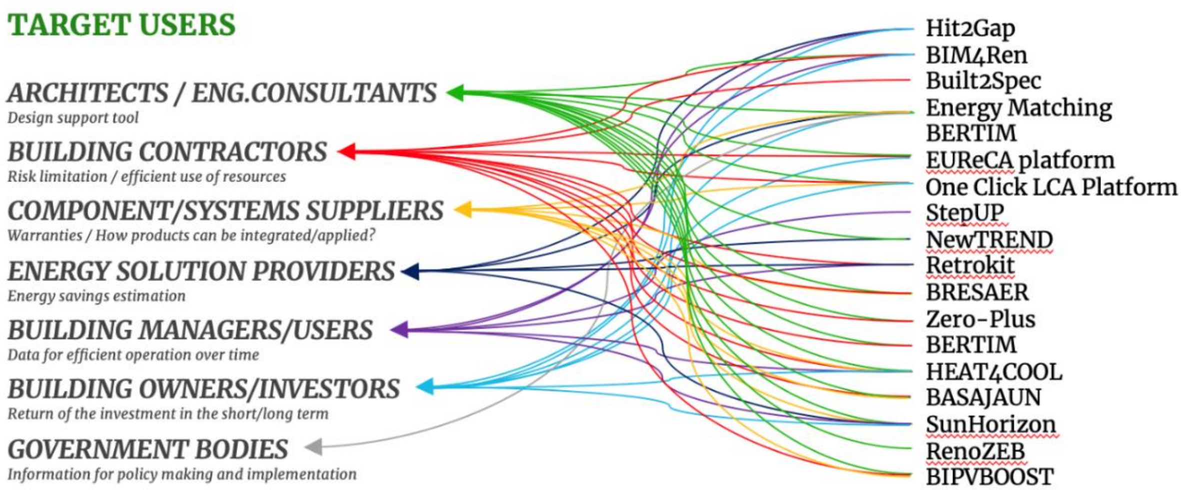

Figure 4.1. Analysis of existing platforms

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The identified inputs and outputs considered in the data flows of the reviewed platforms are presented in table 4.2. Regarding the inputs, it is clear that most of them refer to information from the existing building, its envelope, and services. Moreover, 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 Model (BIM), energy flows data (consumption and generation), quality check and maintenance reports, LCA analyses, and assessments related to the cash-flow of the intervention.

Table 4.2. Overview of Inputs and Outputs

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 - Installations 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

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5. Renovation process analysis

In an effort to systematise and facilitate decision-making during the construction projects, different phases have been identified (Cooper et al., 2005; 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. The stages are the pre-project, which defines the need for the project; the pre- construction, when an appropriate design solution is developed; the construction, which implements the solution; and the post-construction, which aims at monitoring and maintenance of the project.

In renovations, which are still construction projects, the phases mentioned above apply, as researchers have specified in previous studies (Ferreira et al., 2013; Konstantinou, 2014; Ma et al., 2012). However, since renovation is dealing with an existing building, the pre-project phase includes the analysis and diagnostic of the building to define the intervention's scope. Moreover, the current residents that might continue to occupy during construction have a significant role in the execution phase, such as time planning. Industrialised renovation follows the same phases, but some sub-phases are specific or more essential compared to on-site renovation construction, particularly regarding the existing building analysis, the renovation design, and the components' production.

Particularly with regards to WP1, which aims at the development of a digital platform that supports the renovation process, it is particularly essential to understand the decision-making process and the information that it requires. Such decisions include the following:

- Setting the goals, financing, and which requirements for the renovation influence that.
- Analysing existing building energy performance.
- Design the solution (which components to include and how to be integrated in the mesh).
- Digital workflow development.
- Manufacturing and installation

The phases can also be associated to the Level of detail, as described in the BIM or Building Energy Models (BEM) protocols.

The level of development or detail of a BIM model refers to the information that is relevant to the concrete development of the project and necessary to make tangible decisions. There are six different levels of development that are defined by the American Institute of Architects (AIA). The level of detail designates the entire amount of information that the BIM element will contain for each case study.

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After having decided which aspects of the modelling will be developed, the level of geometric detail will be acknowledged. The quality of a model is determined by the LOD of the project and can designate two different concepts: the level of development and the level of detail. There are six types of LOD according to the 2020 Level of Development (LOD) Specification developed by BIM Forum as a standard (BIMForum):

- **LOD 100:** The information contained in the object is purely visual as it refers to its physical appearance. The object does not contain any additional information.
- **LOD 200:** The object contains a specific parametric dimension, which is the one referring to the space requirements within the model. At this level, size, quantities, form and / or location are approximately defined with respect to the whole project.
- **LOD 300:** This type of object already contains 60% of information. In addition to its geometric dimensions, the object contains functional information. It is the level at which the element is defined graphically, and other data are accurately specified: quantities, size, form and / or location with respect to the whole project.
- **LOD 350:** The object is graphically represented within the Model as a specific system or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. These features can be measured directly from the model without referring to non-modelled information such as notes or dimension call-outs.
- **LOD 400**: An LOD 400 element is modelled at sufficient detail and accuracy for fabrication of the represented component, including detailing, fabrication, assembly, and installation information.
- **LOD 500**: The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. The object is defined geometrically in detail, as well as its position, belonging to a specific constructive system, use and assembly in terms of quantities, dimensions, shape, location, and orientation.

This association is also relevant to the development of the Digital twin and the level of detail it offers at the different phases.

5.1. Phases description

Pre-project

This is the initial phase of the project, with the main task of defining the need for the renovation project, the problems, the ambition. The project budget is

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discussed and the client requirements to be met. Those requirements include sustainability goals, functional adjustments or improvements, health, and safety. Defining the needs, requirements and cost estimates often requires diagnostics of the existing building. Selecting the design team can be considered part of the pre-project phase. The design team can advise on the Project Brief, but the leading stakeholder is the client (building owner, developer etc.)

Concept design

During the Concept design phase, proposals that align with the Site Information and the Project Brief are developed. The Design Concept proposals must also be iterated to accommodate inputs from the design team and from specialist consultants (RIBA, 2020). The concept design includes identification and comparison of renovation strategies, interventions, design principles. Particularly regarding industrialised renovation, the decision on the system and components is part of the concept design. Assessment and optimisation, such as BEM, indoor environmental quality (IEQ), LCA, LCC, are performed, in order to evaluate and select the renovation solution.

Final design

Once the concept design has been concluded and the final solution for the renovation selected, the final design phase focuses on developing design information required to manufacture and construct the project. This included detailed survey of the existing building, often with the employment of technologies life 3d-reconstruction, to develop the technical details and engineering of the retrofitted components. Tender and components specification are developed by the design team, with the involvement of the contractors and sub-contractors.

Execution: Manufacturing, assembly off-site and on-site

In projects, there might be co-occurrence between final design and execution. What differentiated this phase is that no-desk work is included, apart from specific site-requests and troubleshooting. The Execution phase includes manufacturing, assembly, and construction of the components off and on site. With the uptake of the off-site construction, greater emphasis is also placed on the logistics of getting materials and large-scale components to site on time and managing supply chain partners (RIBA, 2020). Compilation of the Building Manual and the completion of Verified Construction Information would be prepared during this phase. The execution results with the completed project and the building handover.

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Post-construction

After the construction is completed, the operation of the renovated building begins. To ensure that the building functions as required, post-occupancy evaluation and operation optimisation loops are needed. Monitoring and post occupancy evaluation serves to identify and implement any adjustments, calibrations or improvements required to the building, day-to-day operations, or policies to meet the needs of all building users.

Table 5.1. Overview of Renovation process phases and tasks

Phase	**1**	**2**	**3**	**4**	**5**
Name	Pre-project	Concept design	Final design	Execution and hand-over	Post-construction
Description	Defines the need for the project, the problems, the ambition. Setup 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 industrialised components design concept Assessment and optimization Preparation of permit applications	Detailed design for industrialised 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 optimisation 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

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5.2. Stakeholders overview

Understanding the decision-making and the implementation of renovation projects, and the market actors responsible for the initiative and realisation is paramount to facilitate the decision-making process, resulting in better solutions and improved cost and time efficiency, which is the main objective of the ENSNARE project. To this end, the stakeholders are one of the axes around which the Digital Platform should be organized.

In the building market, we can identify three categories of actors (Avelino & Wittmayer, 2016). Each category has distinct roles and influences in developing the built environment, particularly in the renovation implementation. Those categories can be in general classified in Policy, such as municipalities or cities, who will determine the policies to support and promote renovation; Community, such as Housing association and Private housing owners, who are the renovation beneficiaries; and Market, who are the parties delivering the renovation.

The analysis of existing platforms, in Section 4.1, resulted in the stakeholder types that are targeted as the platform's users. Moreover, Section 5 discussed the renovation process and identified the groups involved in the different phases. Table 5.2 links the stakeholder type with the stakeholder group, and therefore the respective role during the renovation. The stakeholders' overview has been used in the questionnaire to discuss the roles of the stakeholders in the Digital Platform implementation.

The stakeholders identified in Table 5.2 can be found in the three categories found in the building market. The policy and community stakeholders can broadly be grouped as the client. At the same time, the market is linked to the supply chain realizing the renovation, which includes the design and construction team and the specialist consultants. Nevertheless, market actors, such as real-estate developers and investors, could also be considered part of the client team.

An indicative list of business and company types that correspond to those stakeholders is also presented in Table 5.2. The list is not intended to be exhaustive but to clarify the stakeholder types. It should also be considered that the type of businesses might differ per country and project due to different supply-chain structures. For example, an architectural firm, which is part of the design team, can also be responsible for the construction and the subcontractors' coordination, extending its role to that of the construction team. Similarly, an institutional building owner, like a housing association or a municipality, often have in-house design experts and consultants. The platform's user should, thus, identify their role in the renovation process rather than their professional affiliation.

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Table 5.2. Stakeholder's overview

Stakeholder type	**Stakeholder group**	**Business type**
Architectural Designers	Design team	· Planning and construction party · Urban planner · Architect
Building Engineering consultants	Design team Specialist consultants	· Engineering consultants · MEP consultants · Sustainability consultants
Construction companies	Design team Construction team	· General contractor · Subcontractor · Installer · One-stop-shop
System suppliers	Construction team	· Supplier of products or technologies · Supplier of concepts or systems
Energy solution provider	Design team Construction 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
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

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6. ENSNARE WP1 Experts' Questionnaire

An experts' questionnaire was set up as one of the activities for the definition of the specifications for the Digital Platform, aiming to identify the key features for the prospective users of the tool from the point of view of relevant stakeholders from the assembled consortium. Hence the main objective of the questionnaire was to gather relevant information in a systematic and organised manner, from a sample of professionals from different fields with experience in renovation projects. The questionnaire was developed through an iterative process considering inputs from consortium partners along different meetings.

6.1. The questionnaire set-up

The experts' questionnaire was deployed as an online form to be filled in by professionals from the participating institutions of the ENSNARE consortium, benefitting from having different stakeholders and profiles with relevant experience in the building renovation process. It was distributed via e-mail, with the gathering of the responses taking place during May 2021. The project's participants were also requested to distribute it further in their organisation and relevant contacts. With this approach, the targeted respondents' group consisted of researchers and professionals, experienced on the topic of energy renovation. The next section analyses in more detail the respondents' expertise. The participants data are anonymised, and the participants had to give their informed consent to analyse their responses at the beginning of the questionnaire.

The questionnaire is structured in three sections: (I) General information about the respondents and the organisation they represent; (II) General experience about the building renovation process; and (III) Specific experience: involvement in the different renovation phases. The first section aimed at characterising the group of respondents. The second section aimed at reaching a common understanding of general aspects of the building renovation process, validating the prior definition of sequential phases and the involvement of different stakeholders, besides exploring main perceived bottlenecks throughout these phases, from the point of view of the consortium members. Lastly, the second section dealt with the specific information flow at each one of the previously identified renovation phases, identifying the main outputs and most relevant types of inputs required by the respondents to conduct their tasks within the renovation process. The bulk of the questionnaire comprised multiple choice questions, based on a review of previous research experiences to produce comprehensive options; with a handful of open questions only when an open exploration into certain topics was deemed necessary.

The sample description

Forty-two complete questionnaires were gathered after the campaign was over, considering different stakeholders within the consortium. Figure 6.1 shows the number of respondents distributed according to the declared core business of their organisations. 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 previously identified teams (client, construction, design, and energy, as shown in figure 6.2), assuming the experience of building engineering consultants in design stages; nonetheless, the client team remains underrepresented in the responses, which needs to be considered when assessing the results.

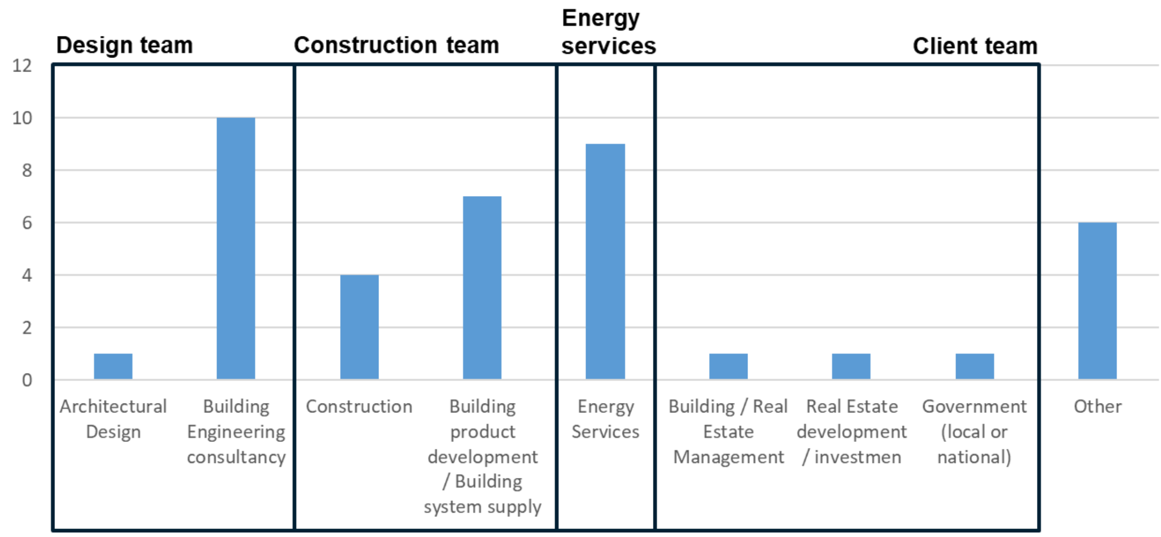

Figure 6.1: Core business of the organisations represented by the respondents (self-declared).

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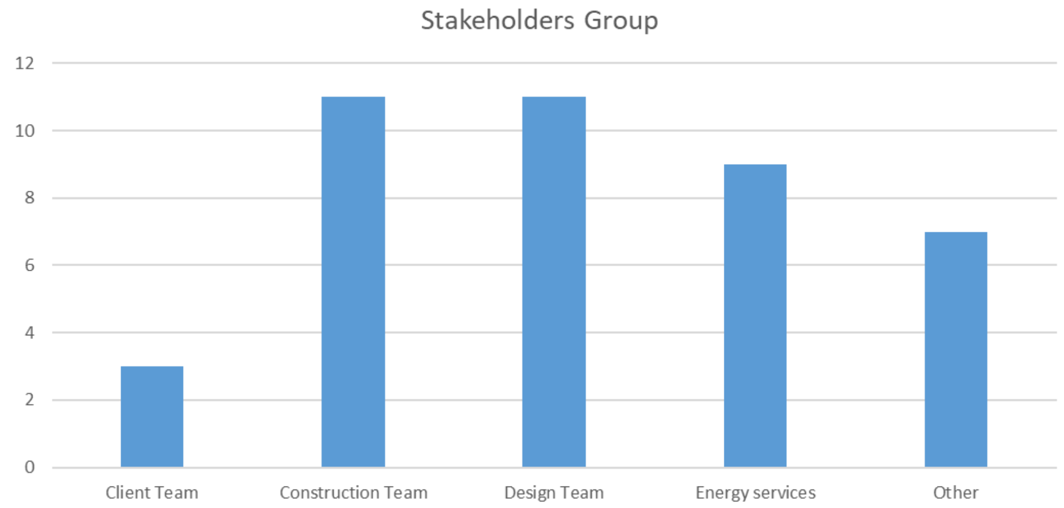
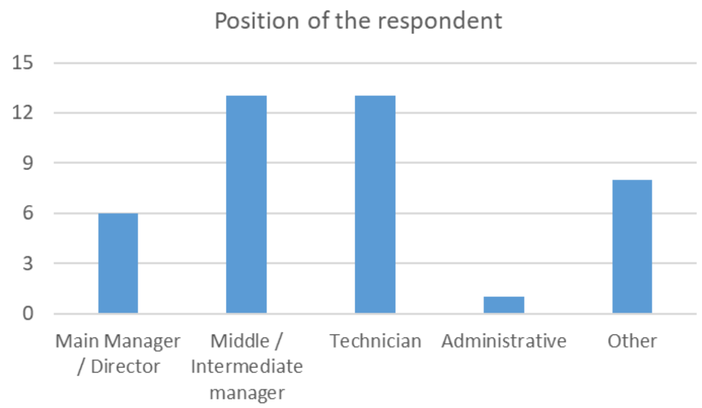


Figure 6.2: Organisations represented by the sample categorised in stakeholders' teams

Regarding the position of the respondents within the institutions they represent, most of them are middle managers (n=13) and technicians (n=13) (figure 6.3); 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 6.4).



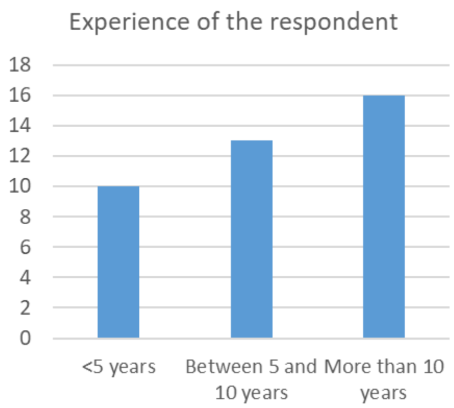


Figure 6.3: Position of each respondent within their organisation; Figure 6.4: Declared experience of each respondent

6.2. Analysis of the responses

The assessment of the responses is structured in three main sub-sections, showcasing and discussing the main findings from the questionnaire concerning (I) General information about the building renovation process; (II) Relevant bottlenecks per renovation phase; and (III) Common required inputs and main outputs per renovation phase.

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General information about the building renovation process

The questionnaire aimed to provide insights to the building renovation process, besides serving as a medium to find common ground on certain definitions among the consortium partners. In that sense, a first exercise was conducted prior to the questionnaire to reach an understanding and define the main phases within the building renovation process, based on the partners' expertise, the revision of specialised literature, and an overview of research projects on the topic. Hence the five defined phases were used as the basis for the questionnaire, with a brief description being provided to the respondents in the form of the table presented in Table 5.1. Thus, these defined phases need to be kept in mind for the interpretation of the results of the questionnaire.

Stakeholders' involvement per phase (Q7-Q11)

Figure 6.5 shows the responses of the sample to questions 7-11, aimed at identifying the involvement of each defined stakeholder type at the different pre-defined renovation phases. Thus, the respondents were asked to state per phase, if they thought each stakeholder is involved, to map their participation throughout the process. The graph then shows the amount of respondents that stated that each particular stakeholder plays a role at any given phase (phases are ordered and colour coded for each stakeholder).

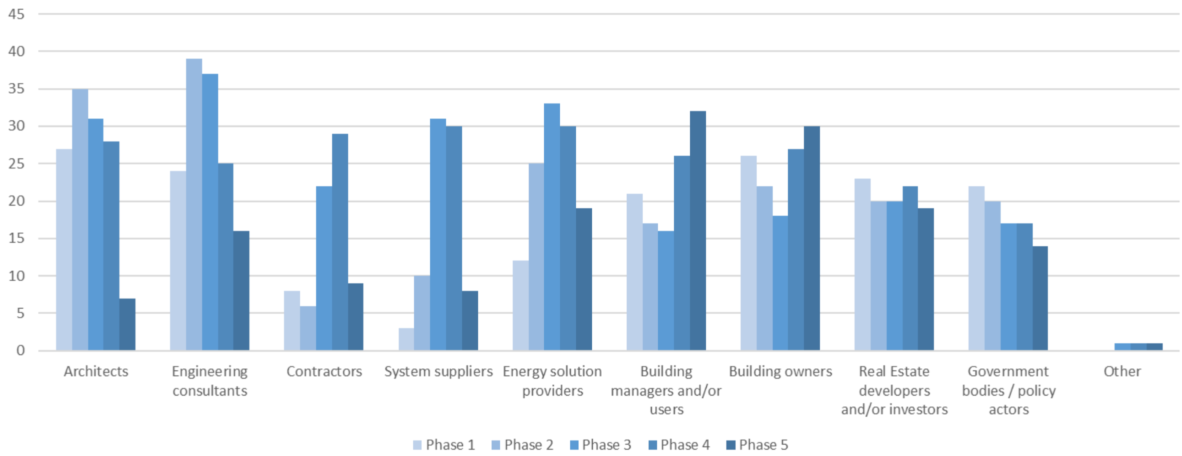

Figure 6.5: Stakeholders' involvement per phase declared by the respondents

The answers were organised 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 6.6, 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

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consultants) is perceived as 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 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).

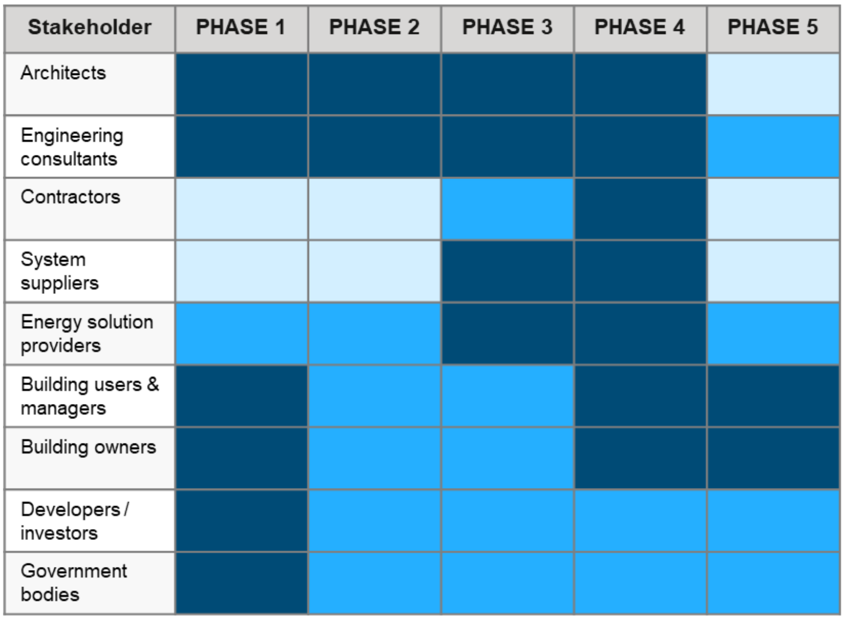

Figure 6.6: Stakeholders' involvement per phase categorised in ranges (low/medium/high perceived involvement, with darker colours signalling a higher perceived involvement within the renovation process).

Perception of the relevance of various factors related to the renovation process (Q13, Q15)

Figures 6.7 and 6.8 show how the respondents answered to questions #13 and #15, aimed at assessing the perception of the relevance of several factors during the renovation process. The former asked for the perceived relevance from the point of view of potential clients, according to the respondents; while the latter asked for their own perception, from an expert's standpoint.

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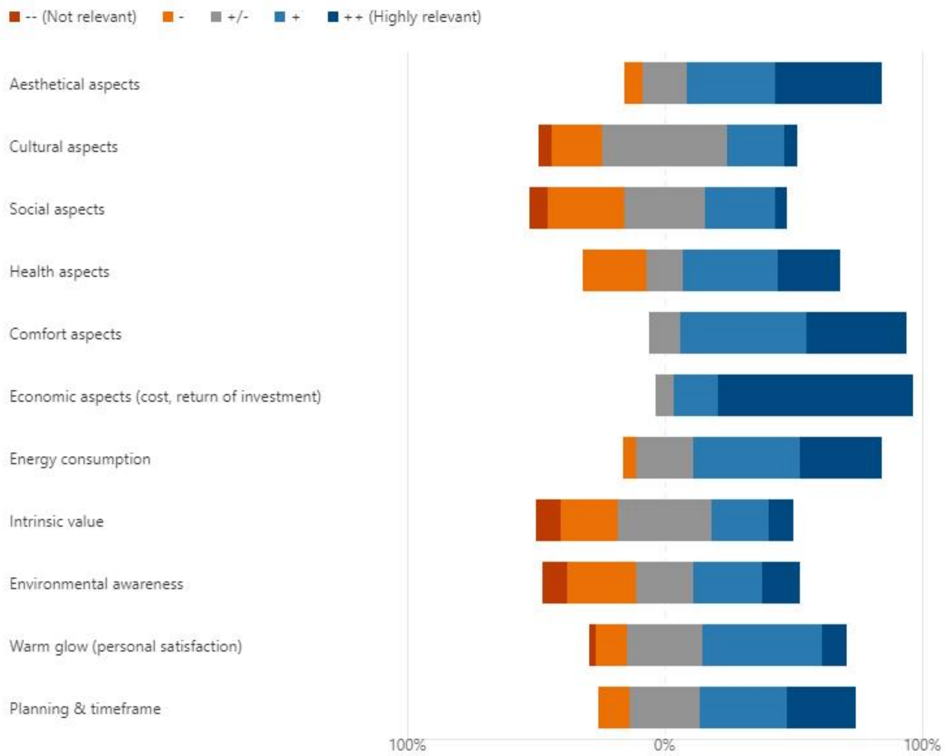

Figure 6.7: Potential clients' perception of the relevance of various factors, according to the respondents

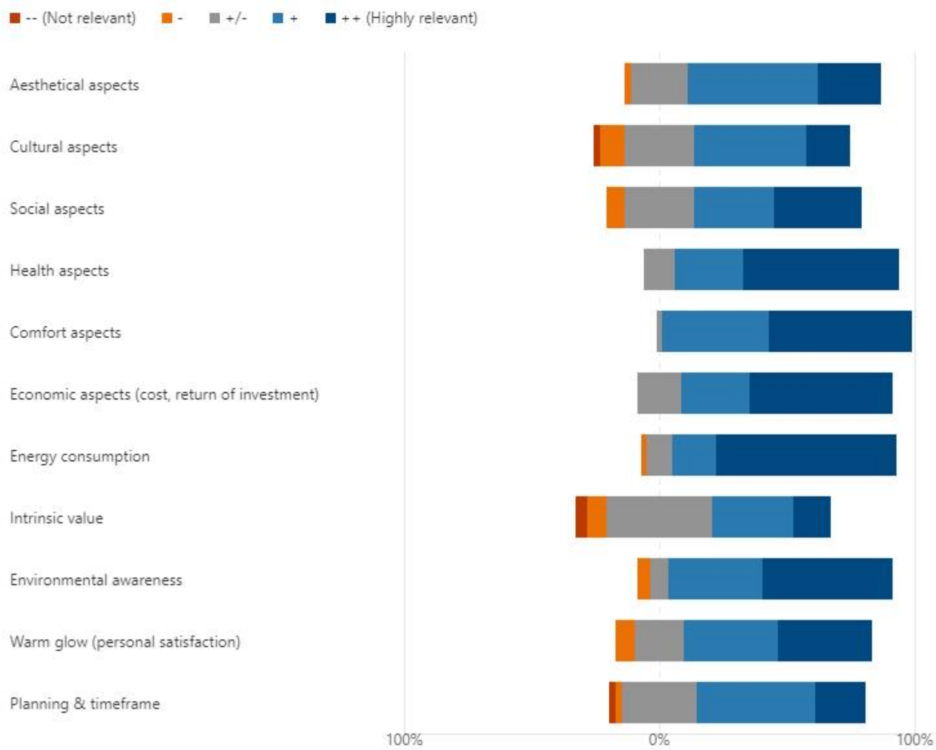

Figure 6.8: Respondents' own perception of the relevance of various factors related to the renovation process

According to the respondents, when it comes to potential clients (figure 6.7), the most relevant aspects are aesthetics, comfort, energy consumption and economic aspects; the latter being perceived as the most relevant among them. On the other hand, the general perception of the sample is that intrinsic value, environmental awareness, social and cultural aspects are the least relevant for potential clients.

When it comes to their own perception, all aspects received higher marks from the respondents in terms of their perceived relevance (figure 6.8), with comfort aspects being judged as the most relevant overall. Other aspects markedly judged as highly relevant are energy consumption, environmental awareness, health, and economic aspects. Hence, the main difference between these two sets of answers is the idea that clients may have aesthetical aspects in higher regard (based on the experts' experience), while the experts themselves think that health aspects and environmental awareness deserve higher recognition.

Main perceived bottlenecks per renovation phase

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 phase. These questions were open ended, so the respondents were free to state the bottlenecks they perceive as important at each phase. All the answers (for all phases) are shown in figure 6.9, depicted in the form of a word cloud where word sizes illustrate the number of times they were freely mentioned by the sample.

Figure 6.9: Word cloud of all the mentioned bottlenecks

The open answers obtained by the sample were then assessed through content analysis techniques, to identify the main types of bottlenecks discussed by the experts. This 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. The list of main bottlenecks is as follows:

- LACK OF INFORMATION
- UNCLEAR DEFINITIONS
- NORMATIVE & COMPLIANCE
- COORDINATION & COMMUNICATION
- RESPONSIBILITES & GUARANTEES
- UNRELIABLE ASSESSMENTS
- TECHNICAL CHALLENGES
- OTHERS

The responses were then re-assessed and categorised based on the list of main types of bottlenecks, with the result being shown in figure 6.10. 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 & compliance aspects throughout the process. The detailed mentions within each bottleneck type will be expanded in the following sections, discussing their perceived relevance and impact per renovation phase.

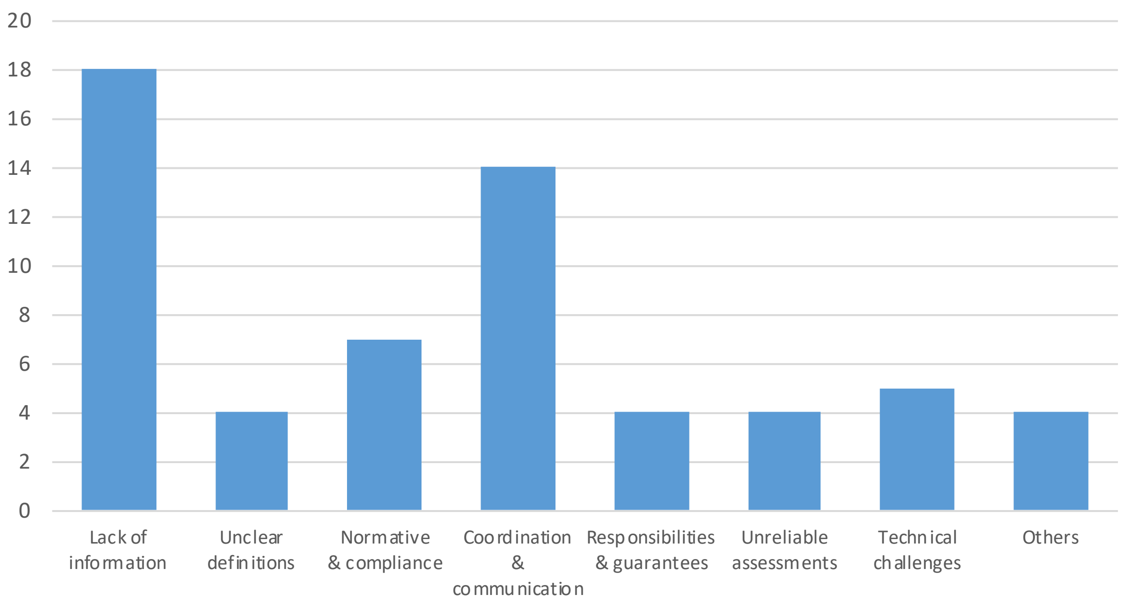

Figure 6.10: Main types of bottlenecks identified from the responses and frequency of their mentions

Main identified bottlenecks in PHASE 1: Pre-project (Q23)

Figure 6.11 shows the word cloud of responses for the pre-project phase (phase 1), while figure 6.12 shows the responses categorised in the main types of bottlenecks identified. The colours in figure 6.12 (and all subsequent figures of the same type) illustrate the amount of mentions for each bottleneck type within each phase, thus the darker the colour, the higher the amount of mentions from the sample.

From the word cloud it is clear that the main issues in this phase refer to design, followed by energy consumption and information. The detailed analysis of the responses shows that by far the main bottlenecks at this phase refer to the lack of available information to support the early decision-making process, explicitly in terms of limited technical information about the existing building, and limited energy consumption data that might help estimate the potential impact of a renovation project. Second to this, there were mentions of unclear definitions of the renovation objectives and key performance indicators (KPIs), and unclear potential design proposals at an early stage, which especially hinder the clients' decision-making process.

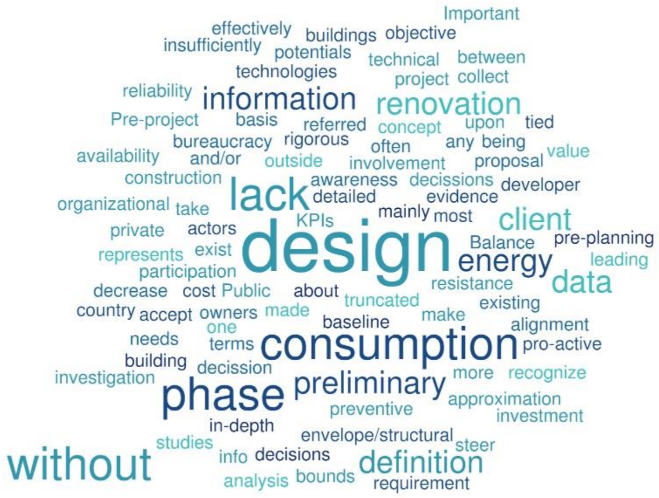

Figure 6.11: Word cloud of all the mentioned bottlenecks for PHASE 1: Pre-project

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LACK OF INFORMATION	UNCLEAR DEFINITIONS	NORMATIVE & COMPLIANCE	COORDINATION & COMMUNICATION
- Limited info about the existing building (construction, envelope, structure). - Limited energy consumption data	- Unclear definition of the renovation objective and KPIs. - Unclear design proposals at this stage hinder the clients' decision-making process.	- Bureaucracy	- Limited involvement and participation of specialists (mostly developer and owner).
RESPONSIBILITES & GUARANTEES	**UNRELIABLE ASSESSMENTS**	**TECHNICAL CHALLENGES**	**OTHERS**
-	- Not enough depth in the technical project to come up with reliable cost estimations.	-	- Lack of interested clients and governmental incentives.

Figure 6.12: Mentioned bottlenecks for PHASE 1: Pre-project, categorised in the identified bottleneck types

Main identified bottlenecks in PHASE 2: Concept design (Q32)

During the concept design phase (phase 2), the focus in design, information and energy was not only maintained but also heightened, clearly showed in the word cloud depicted in figure 6.13. When looking at the categorised responses, the trend of having the lack of information as the most mentioned bottleneck type is maintained, securing it as the most important bottleneck to overcome at the initial stages of a renovation project. Adding to the complaints about limited information about the existing building, there was declared that the lack of technical information about building products ready to be incorporated in the early design stages is a hindrance. Moreover, communication issues between all the involved stakeholders, especially between clients and designers; plus, the low involvement from system suppliers were signalled as important bottlenecks to consider. Finally, there were also mentions of unreliable assessment tools to easily compare different design options and predict their performance, and general complaints about bureaucracy as an obstacle.

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Figure 6.13: Word cloud of all the mentioned bottlenecks for PHASE 2: Concept design

LACK OF INFORMATION	UNCLEAR DEFINITIONS	NORMATIVE & COMPLIANCE	COORDINATION & COMMUNICATION
- Limited info about the existing building and its use. Not enough technical information about building products. - Limited availability of project information (drawings & specifications).	-	- Bureaucracy - Unclear overview of National or local normatives that need to be followed.	- Communication issues and limited information exchange between stakeholders. - Unclear client-designer communication. - Low involvement and response time from system suppliers.
RESPONSIBILITES & GUARANTEES	**UNRELIABLE ASSESSMENTS**	**TECHNICAL CHALLENGES**	**OTHERS**
- Unclear responsibilities of the local architects and other stakeholders.	- Unreliable assessment and optimisation of different design options. - Uncertain building energy performance predictions. - Unreliable cost predictions of energy services.	-	- Lack of skilled professionals to assemble a consortium.

Figure 6.14: Mentioned bottlenecks for PHASE 2: Concept design, categorised in the identified bottleneck types

Main identified bottlenecks in PHASE 3: Final design (Q41)

During the final design phase (phase 3) there seemed to be a shift in what are perceived to be the main bottlenecks, towards coordination aspects. Nevertheless, mentions of bottlenecks were fairly distributed among coordination & communication, lack of information, responsibilities & guarantees, and unclear definitions. Within the phase, coordination issues referred to unclear involvement and collaboration between different stakeholders (especially related to the input from system suppliers), and lack of a central point for information. The unclear involvement from stakeholders is also connected to the lack of clear

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responsibilities and liabilities at the procurement stage, which was mentioned to be a relevant cause for misunderstandings, conflict, and delays. Regarding the declared lack of information, mentioned aspects referred to the lack of technical information and design alternatives from systems suppliers, which appears as an obstacle for the comprehensive incorporation of building products and installation details in the final design and tender.

Figure 6.15: Word cloud of all the mentioned bottlenecks for PHASE 3: Final design

LACK OF INFORMATION	UNCLEAR DEFINITIONS	NORMATIVE & COMPLIANCE	COORDINATION & COMMUNICATION
- Unclear design alternatives from suppliers. i.e. what colours, materials and shapes are possible. - Unclear detailed info on connections and installation materials.	- Unclear technical solutions and installation techniques for budget calculations and procurement.	- Approval of the project by local authorities.	- Coordination issues and clear involvement among consortium members. - Lack of a central access point of information - Collaboration between different suppliers.
RESPONSIBILITES & GUARANTEES	**UNRELIABLE ASSESSMENTS**	**TECHNICAL CHALLENGES**	**OTHERS**
- Unclear responsibilities and liabilities at the procurement stage for quality checks, delivery, defects and replacements during and after construction.	-	- Integration and fine tunning of all the elements and components.	- Lack of skilled professionals to assemble a consortium.

Figure 6.16: Mentioned bottlenecks for PHASE 3: Final design, categorised in the identified bottleneck types

Main identified bottlenecks in PHASE 4: Execution and handover (Q48)

At phase 4: execution and handover, the main perceived bottlenecks fully shifted towards coordination & communication issues off and on-site, followed by technical challenges mostly derived from clashes between the design of the façade components and their installation on-site. Although it was stated that there is not always enough technical information, the fact that lack of information received lower mentions as a group, compared to previous phases, clearly shows that this

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is not the main source of problems within this phase, which revolves around construction and the role of partners, as evidenced in the word cloud in figure 6.17. Going further into detail, as shown in figure 6.18, communication & coordination problems during the stage explicitly referred to the lack of clear communication channels between all stakeholders, especially regarding communication with owners and users, and the coordination between contractors and the supply-chain.

Figure 6.17: Word cloud of all the mentioned bottlenecks for PHASE 4: Execution and handover

LACK OF INFORMATION	UNCLEAR DEFINITIONS	NORMATIVE & COMPLIANCE	COORDINATION & COMMUNICATION
- Not always enough technical information about the renovation components (façade panels)	-	- Permits and green light from the local authorities and the client.	- On and off-site logistics and work-flow. - Unclear communication channels between stakeholders and coordination issues between the supply-chain and contractors. - Unclear communication with owners and users.
RESPONSIBILITES & GUARANTEES	**UNRELIABLE ASSESSMENTS**	**TECHNICAL CHALLENGES**	**OTHERS**
- Unclear agreement of responsibilities between consortium partners.	-	- Design and maintenance of the envelope. - Errors in accuracy might jeopardize the installation on-site. - Lack of standardisation.	-

Figure 6.18: Mentioned bottlenecks for PHASE 4: Execution and handover, categorised in the identified bottleneck types

Main identified bottlenecks in PHASE 5: Post-construction (Q55)

Lastly, when it comes to the post-construction phase (phase 5), once again the main source of issues was perceived to be the lack of information. From a general

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perspective, this refers to the fact that post-occupancy monitoring and evaluation is still rarely performed, so there is a general lack of information on the overall process to fully define bottlenecks based on the expertise of the sample. On the other hand, there is also a perceived particular lack of information regarding comprehensive monitoring data and limited and partial information on users' schedules and operational data, which comes across as a hindrance to an optimal management and efficient use of the building.

Figure 6.19: Word cloud of all the mentioned bottlenecks for PHASE 5: Post-construction

LACK OF INFORMATION	UNCLEAR DEFINITIONS	NORMATIVE & COMPLIANCE	COORDINATION & COMMUNICATION
- Post-occupancy evaluation is still rarely performed. - Limited access to monitoring data, which is usually fragmented. - Limited info on users' scheduled.	-	-	-
RESPONSIBILITES & GUARANTEES	**UNRELIABLE ASSESSMENTS**	**TECHNICAL CHALLENGES**	**OTHERS**
-	-	-	- Lack of incentives for landlords in tenant-based scenarios.

Figure 6.20: Mentioned bottlenecks for PHASE 5: Post-construction, categorised in the identified bottleneck types

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Specific information per phase (main required INPUTS and main OUTPUTS per phase)

Personal involvement of respondents (Q17, Q24, Q33, Q42 & Q49)

The questionnaire aimed at gathering specific information from each distinct renovation phase. For this purpose, it was asked to the sample to declare their personal involvement and expertise in each one of them, to get this information from primary sources. Thus, questions about each phase would only be available to the respondents if they had previously declared to have experience in carrying out any of the tasks that were defined per phase. It seems important to point out that this also applies to the aforementioned identification of the main bottlenecks at different renovation phases. Figure 6.21 shows the detailed expertise of the sample within the renovation process, which gives further insights to their answers. The majority of the sample is involved in phase 2: concept design, followed by their participation in phase 1: pre-project. On the other hand, less than a third of the sample declared to be involved in phase 5: post-construction (n=12); a fact that needs to be kept in mind when assessing the results.

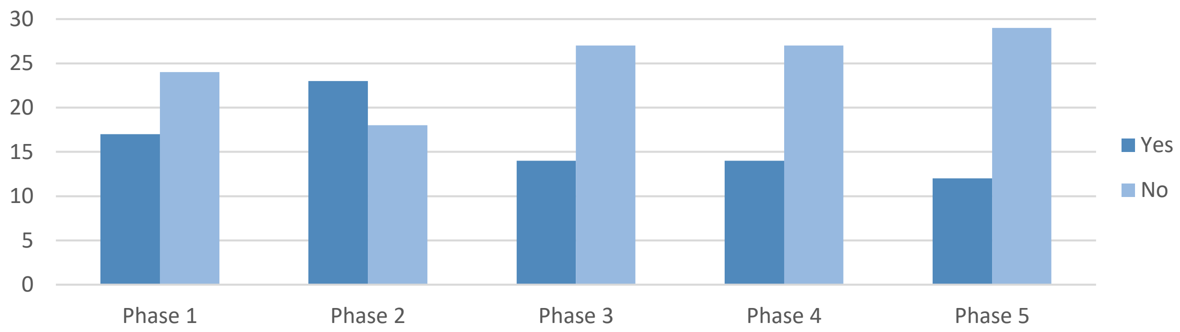

Figure 6.21: Declared personal involvement of the respondents in each renovation phase

Main required INPUTS per phase (Q20, Q27, Q36, Q45 &Q52)

The main questions at each phase aimed at identifying the main inputs and outputs that the Digital Platform would have to consider throughout the process. To that end, the respondents had to first declare what are the inputs they commonly require to carry out the tasks they need to perform during the renovation process, at each phase. A list of inputs was provided based on a previous revision of research projects, digital platforms, and literature on building renovation; however, the respondents had the possibility to add more (under "others") in case they feel the list was not comprehensive enough.

Figure 6.22 shows the responses from the sample at each renovation phase. The fact that phases 1 & 2 show a higher number of responses in comparison to other phases only follows the number of respondents with declared experience in each

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one, previously depicted in figure 6.21. Hence, since the sample varies among phases, a direct comparison between them is not possible, limiting the assessment at phase level to identify the relative pre-eminence of certain inputs for the involved respondents.

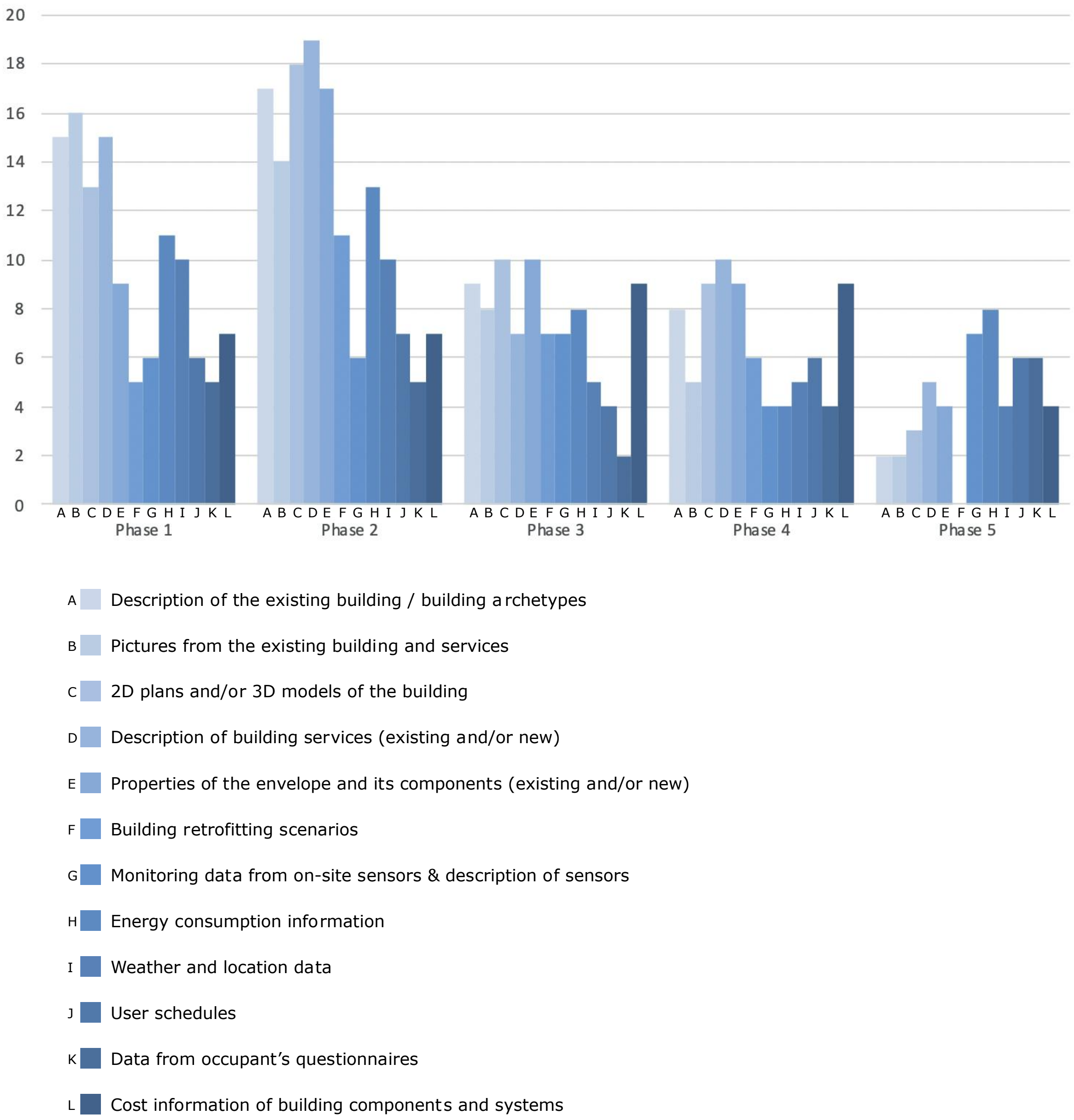

Figure 6.22: Main INPUTS required to conduct the respondents' tasks at each renovation phase

The relative relevance of each pre-defined type of input is depicted in figure 6.23, following the same colour coding used to highlight the involvement of the different stakeholders throughout the different phases (figure 6.6). Thus, low, medium, or high relative mentions per phase are shown with colours (the darker the colour,

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the higher the number of mentions per phase). In general, it is possible to see that the main required inputs declared by the consortium referred to information about the existing building, its services, and its envelope, which is needed during phases 1-4, while cost information of components and systems is relevant at phases 3 & 4. Finally, during phase 5, the main required inputs shift to operational information, as expected (monitoring info, energy consumption, user schedules and occupants' data).

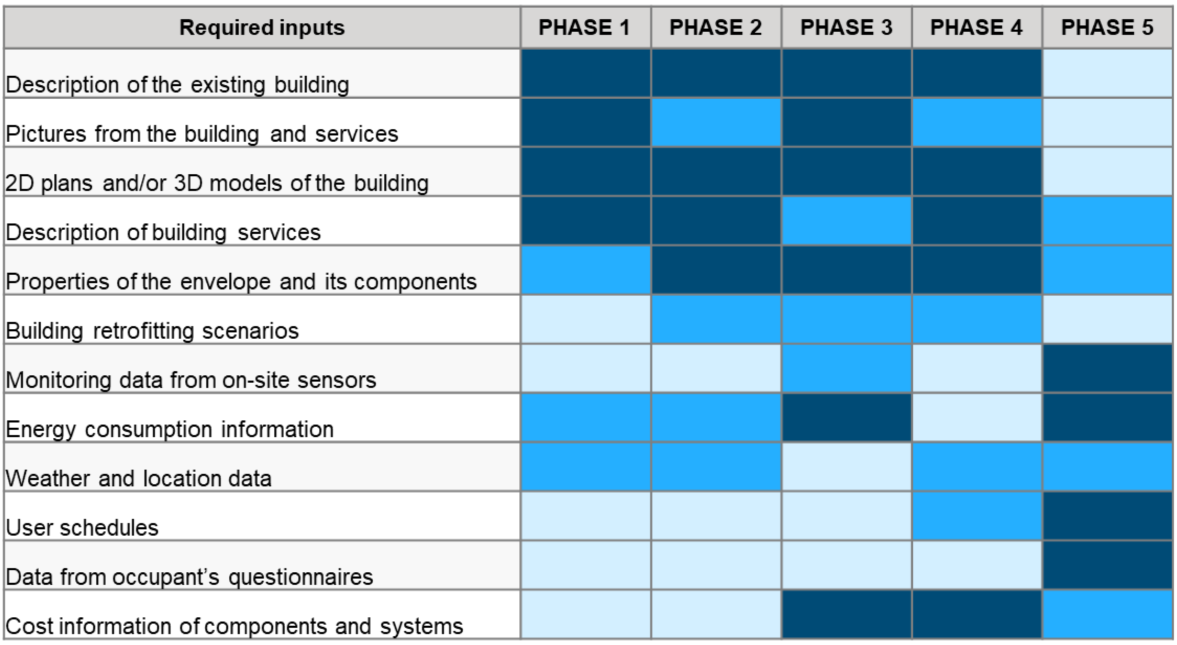

Figure 6.23: Overview of the main required INPUTS per phase according to the respondents' mentions. Low/medium/high relative mentions per phase are shown with colours (the darker the colour, the higher the number of mentions per phase).

Main OUTPUTS per phase (Q22, Q29, Q38, Q47 & Q54)

The same exercise was conducted to identify the main outputs from the respondents at the different renovation phases, based on their role throughout the process. Figures 6.24 and 6.25 show the main outputs declared by the consortium partners, highlighting the definition of envelope retrofitting scenarios, energy consumption definition, cost assessments, and installation guidelines. First, the definition of envelope retrofitting scenarios occurs during phases 1-3, being established as the core output of the initial tasks. Second, the definition of building energy consumption seems to be a recurrent output at phase 1 and at phase 5, where it is also combined with indoor comfort assessments. Similarly, guidelines for installation/assembly, and logistics/planning were heavily focused outputs during phase 4: execution and handover. Finally, cost assessments as an output of different tasks were found to be relevant throughout the renovation process, with a particular emphasis on phase 4.

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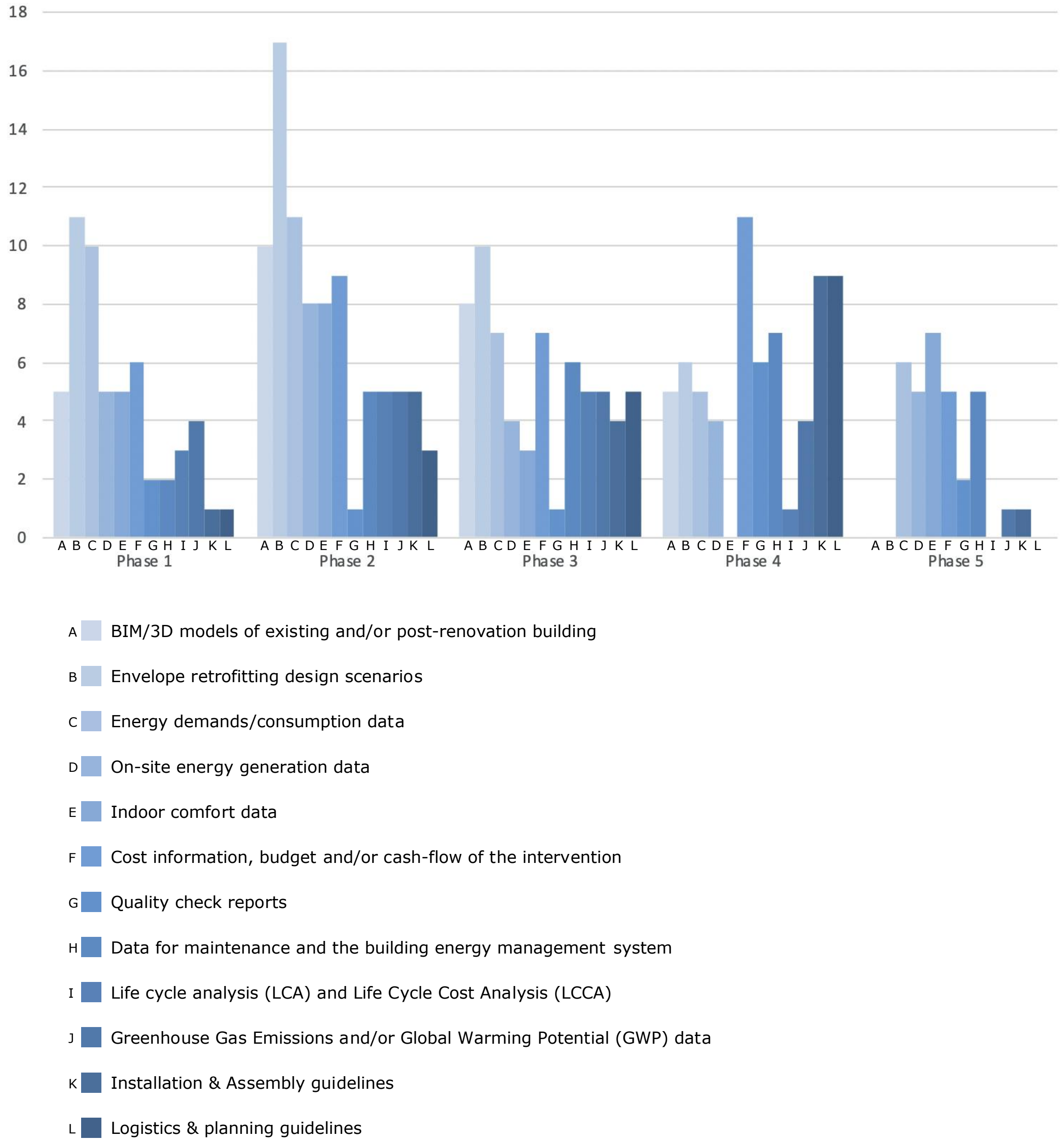

Figure 6.24: Main OUTPUTS declared by the respondents based on their tasks at each renovation phase

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Main outputs	PHASE 1	PHASE 2	PHASE 3	PHASE 4	PHASE 5
BIM/3D models					
Envelope retrofitting design scenarios					
Energy demands / consumption data					
On-site energy generation data					
Indoor comfort data					
Cost, budget and/or cash-flow info					
Quality check reports					
Data for maintenance and BMS					
LCA and LCCA					
Greenhouse Gas Emissions and/or GWP data					
Installation & Assembly guidelines					
Logistics & planning guidelines					

Figure 6.25: 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).

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7. Workshop

An experts' workshop was organised as a second step of the systematic data gathering activity initiated by the questionnaire. Hence, it was structured around the results obtained from the questionnaire, with the aim of both validating these findings reaching a consensus through further discussion and operationalising the compiled information into useful inputs for the development of the DP4ER specifications and the work of other WPs within the project.

The main aspects discussed during the workshop were as follows:

- Definition of the target stakeholder(s) for the platform throughout the different renovation phases.
- Reflection on the main identified bottlenecks throughout the process, how can they be overcome by the Digital Platform to reach meaningful reductions in cost and time.
- Establish correlations between the renovation phases, the required inputs and the main outputs from the different stakeholders and work packages.
- Identification of the information required by the tools to be developed in the different WPs, considering the level of detail of such information at the distinct phases.
- Design of the renovation process workflow to be considered as basis for the Digital Platform.

7.1. Workshop structure

The workshop considered all stakeholders within the ENSNARE consortium, and was held online on the morning of June 4th, via Microsoft Teams. The workshop was structured in two rounds, which started with a brief presentation of selected results from the experts' questionnaire, to then move to group discussions in breakout rooms to elaborate on them and provide feedback. The web-based platform MIRO (Miro, Online whiteboard tool) was utilised as a means of guiding the discussion and writing down the highlights in each room, which were moderated by two assigned ENSNARE partners (one leading the discussion and the other taking notes in the MIRO board). The working material produced during the workshop are available in APPENDIX 3. The two discussion rounds are detailed below.

Round 1: Validation and elaboration of the questionnaire results

The aim of this round was to disseminate and validate central findings from the questionnaire among the consortium partners, to provide a collective

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understanding for the further development of the Digital Platform and overall project.

The results presented here referred to the perceived involvement of the different stakeholders throughout the renovation process, the perceived relevance of certain aspects related to it, and the main perceived bottlenecks at the different renovation phases. Accordingly, the discussion centred around two questions: (a) Who should be the target group/user of the platform? And (b) How can the bottlenecks be improved through the Digital Platform? The discussion was carried out in four parallel groups where the participants were assigned based on their complementary expertise, ensuring a mix within each group. At the end of the group discussion, the main highlights from each group were presented in the plenary session to allow for general comments.

Round 2: Operationalisation of the questionnaire findings for the design of the Digital Platform workflow

The second round aimed at defining a typical workflow for a renovation project, considering the tasks that are carried out by all involved stakeholders, the inputs they require for them and their main outputs. More importantly, the discussion aimed at establishing relationships between inputs and outputs throughout all renovation phases to develop a continuous workflow, defining important milestones and relevant aspects to consider derived from the practical experience of all partners.

The round started with a presentation of the main inputs and outputs at each renovation phase, identified through the questionnaire. Afterwards, the discussion was carried out in two parallel rooms, identifying the relationships between inputs and outputs, and specifying the format and level of detail needed for the information flow at the distinct phases. Moreover, one of the groups was asked to pay special attention to the digital aspects that need to be considered during the workflow, while the second was tasked to especially consider the physical aspects of the renovation solutions at hand. The former group was led by TECNALIA and TU Delft, while the latter was moderated by ABUD, CIVIESCO and TU Delft.

7.2. Results

Platform Users

First, it is important to state that the definition of the target user is not meant to exclude stakeholders, but rather to clearly identify who would actively use the DP4ER as a marketable product to support the renovation of buildings. Nonetheless, all the involved stakeholders would need to provide inputs and

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feedback during the renovation process. The main user of the platform is further referred as the "technical user", who would be the responsible for managing the platform and directing the interaction of the other involved stakeholders.

Thus, regarding the potential target user(s) of the platform, it was widely agreed that, as a general scenario, the design team should be in the lead until project completion as the main coordinators of the process, considering architects and engineering consultants. This directly follows the results of the questionnaire regarding the involvement of the different stakeholders throughout the process, observing a high involvement of the design team on phases 1 to 4. Thus, this positions the design team as the most generally accepted technical user of the Digital Platform, being the stakeholder(s) in charge of directly interacting with it, as a support tool for the general coordination and communication activities throughout the process. Under that assumption, the idea would be to use the platform to receive technical input from other stakeholders; and use it to comprehensively inform the client team to assist a swift decision-making process throughout all phases.

Nonetheless, when it comes to the use of the Digital Platform in phase 5 (post-construction and building operation), it was agreed that the focus drastically shifts to the client team, especially building managers and professionals in charge of optimising the operation of the renovated buildings. Hence, at phase 5, the ENSNARE consortium envisions that building managers and owners would become the main technical user of the platform, with relevant input from energy solution providers. Furthermore, even though the design team is perceived as the main technical user during the renovation project, it is foreseen that the construction team will likely have a larger role during phase 4: execution and handover, in cases and contexts where the design team is not directly in control of the construction process. In those cases, the construction team might take the lead when it comes to the platform, but it is still perceived as the exception by the ENSNARE consortium.

The scheme in figure 7.1 shows the different identified stakeholders and highlights their involvement throughout the renovation process. It also indicates the main outcomes and information that they would seek from the Digital Platform, based on their tasks and roles.

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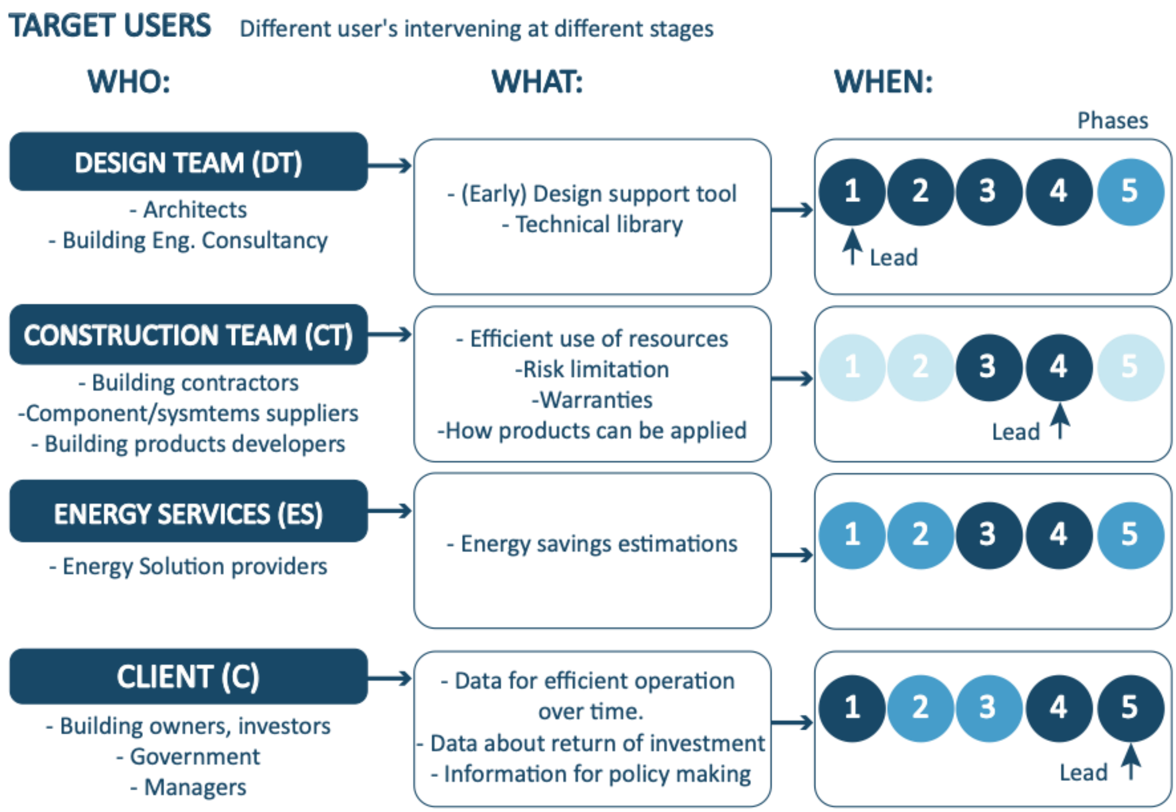

Figure 7.1. Overview of the stakeholders' groups and their input during the distinct phases

Bottlenecks in the process

The discussion about the potential of the Digital Platform to improve the identified bottlenecks during renovation processes circled around the two main ones: (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, that deal with the design of the 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.

The discussion aimed at identifying certain aspects that need to be addressed and considered during the development of the platform, to help overcome these bottlenecks, which will be discussed separately.

Lack of Information

First, it was mentioned that it is important to establish who is responsible for gathering the information needed at each phase. Moreover, to support this, it was

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agreed that having a comprehensive building data checklist is necessary, considering the level of detail for said information at every step of the process.

Nevertheless, even if responsibilities and data gathering activities are clearly defined, there is a relevant information gap at early design stages, especially related to technical information that could otherwise serve as valuable input for the concept design. For this, it was proposed to consider an overview of technical solutions within the DP4ER, in the form of a technical library of building components and systems with standardized factsheets, able to be expanded over time to support early design tasks. Furthermore, it was mentioned that a building reference library would serve as a relevant complement, considering building archetypes 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.

Coordination and Communication

Regarding coordination and communication issues, in general it was perceived 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. In this regard, fostering clear information exchange was stated to be a key issue to overcome most bottlenecks during the process.

Moreover, it was mentioned that the construction team 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. Finally, it was pointed out that putting a protocol in place for clear and direct communication among the stakeholders could help reduce time throughout the process, besides supporting faster decisions in the face of changes and unforeseen events, especially during the execution phase where on-site events are bound to happen, and delays may have a sizable impact on the budget and on-site logistics. Such a protocol may result on a dedicated tool within the DP4ER to house internal communications within the consortium, where agreements can be reached, and information can be traced back to minimise risk and clearly establish responsibilities and guaranties throughout the process.

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Workflow

As the main result of the discussion, a typical workflow was drafted for a general renovation process, identifying key aspects to keep in mind for the development of the DP4ER. These are organised in phases related to their main objectives as follows.

Phase 1-3: from initial requirements to the final design

During these phases, the design team is the technical user of the platform, using it to generate the renovation scenarios based on the requirements from the client team, feedback from the other stakeholders, and referential information from the Digital Platform. The client team should not necessarily directly interact with the platform at this point, using it instead as an information outlet. Thus, the platform is meant to be used to inform the client of the different scenarios and the overall progress of the project.

During the initial phase, the platform is envisioned mostly as a communication tool. However, it can be used as a design and collaboration tool, where the design and client teams can work together. During this collaboration and correlation of costs and benefits, the project requirements and KPIs are also defined.

Phase 1 mostly deals with referential information to support the initial decision-making process. Here, the DP4ER should provide a straightforward way to collect all required inputs, while minimising the effort from both the client and the design team to get accurate enough scenarios to drive the discussion and define requirements set on realistic savings projections and budget estimations that configure a solid business plan. Relevant information for the client team comes down to the expected energy performance of the renovated building, the cost of the overall intervention, and certain architectural aspects of the proposed solutions that will define the spatial and visual expression of the building (how will it look like). As mentioned in the discussion about the main bottlenecks, it was proposed that DP4ER considers a catalogue of technical solutions (with referential costs and potential performance ranges), and an array of reference building archetypes, to support the initial discussions between the client and the design team.

After the project has been approved by the client, the design team starts working on a concept design for the specific building in phase 2. The design of the renovation concept starts with the development of distinct preliminary scenarios based on the defined requirements. These scenarios are compared in terms of cost, performance, and architectural expression, to find the one most suited to the client's requirements (under their approval). Basic measurements and general information of the existing building are needed at this stage, to produce the

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retrofitting scenarios. Once a concept is defined, it goes through optimisation rounds to enhance its cost-effectiveness, considering a more detailed assessment of the energy consumption prospects under the proposed strategy. At this point, the basic measurements of the building need to be complemented with a detailed building survey and in-depth information about the building systems in place. It is relevant to point out that the generation of scenarios is a key development strategy during the design process, considering different LOD. Hence, the LOD needs to be appropriately managed according to what is needed at each phase.

After the final concept has been approved by the client, the tender begins. During phase 3, the final concept gets detailed, and a BIM model for the project is developed, based on the building survey and technical inputs from suppliers. In this phase the engineering of the components for manufacturing takes place, ending with comprehensive detailed information for the execution. Here, it is important to consider the specific requirements of each supplier, thus technical data and the information from the BIM will need to be filtered to suit each stakeholder, avoiding information overload. During the tender it is especially important to count on clear protocols for communication among the stakeholders to overcome potential misunderstandings, along with establishing clear responsibilities for the detailing and posterior execution. Due to the need for close collaboration, it is envisioned that both the design team and the construction team directly interact with the DP4ER, being perceived as technical users during phases 3 and 4.

Phase 4: execution and handover

The information and communication protocols of phase 3 must extend to phase 4 to keep close communication between the design and construction teams. Moreover, it is crucial to consider a protocol to ensure a flexible information flow to swiftly deal with any changes that may arise during the execution, which otherwise might cause major delays. Thus, the project's technical information needs to be kept up to date by the responsible stakeholders following accessible tools that are flexible enough to accommodate changes, which should be easily informed to the client for their approval through the DP4ER. During this phase, the main technical user of the platform should be the stakeholder responsible of overseen the construction process, which may come from the construction team or the design team, depending on how these roles are commonly defined in the different European countries considered within the ENSNARE project.

Phase 5: post-construction

The biggest shift on the interaction of the identified target users with the DP4ER comes after the project is finished and it is handed over to the client team. From

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there on, the technical user of the platform is envisioned to be the stakeholder in charge of the operation of the building, namely the building manager, or an external advisor responsible for the building performance during its operation. During this phase, detailed information about the performance of the building will be available through the digital twin, which will be connected to the building management system (BMS). The digital twin will then be used to optimise the operation of the building throughout its lifespan.

The schemes in figure 7.2 show the distinct communication protocols envisioned to take place throughout the renovation process, based on the defined workflow. Solid lines and dotted lines represent direct and indirect interactions between the identified stakeholders and the DP4ER, with arrows signalling the direction of the information flow where it applies. Moreover, the stakeholders that appear framed with a rectangle are envisioned to take the lead as the main technical user at each scenario. It is important to reiterate that in the case of phases 3 & 4 this refers to the stakeholder overseeing the execution which may come from either the construction or the design teams, depending on the context.

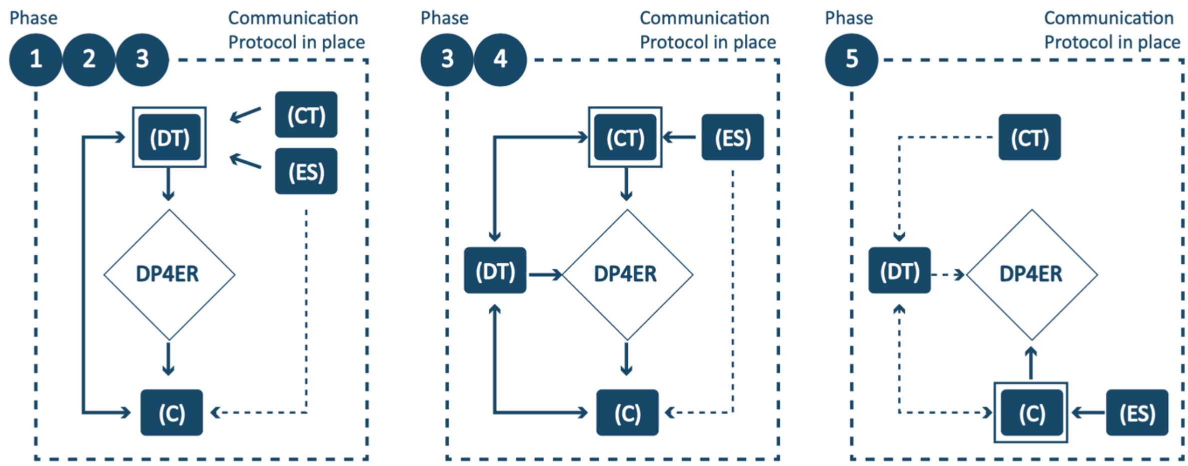

Figure 7.2. Information and communication flow during the phases. In Phase 1 and Phase 2 the Design team (DT) is the coordinator between the stakeholders and the platform. In Phase 3 and Phase 4 the Construction team (CT) is the main of the platform. Finally, in Phase 5 the client (C) is the main user of the platform.

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8. DP4ER specification: Modules and workflow

Based on the analysis described above, we can conclude that the Digital Platform (DP4ER) will consist of different modules. They incorporate sets of tools, such as databases, simulation engines, data collection protocols, models, etc., which are used by the platform to provide the output that is required during the renovation process.

The different modules are defined as separate tools, and they are applied in the different phases of the renovation process. Moreover, they interact with each other, to make the process more efficient. To this end, the different modules aim at supporting different phases, even though their outputs can be used in later phases as well, while they can be used separately depending on the needs of the specific project, but they also interlink to each other, to facilitate the exchange of information.

More specifically, the following modules are defined as the Digital Platforms' tools:

1. Reference module
2. Building data gathering module
3. Early Decision Support Tool module
4. BIM module
5. Coordination and communication module
6. Digital twin module

The following sections describe each module including a definition of the module, the inputs and by which stakeholder team, how they are collected, the output, and, if and how it links to other modules. Figure 8.1 presents an overview of the modules and the workflow of the platform. As shown below, the modules are introduced in different stages, but can also span over the phases. This information comprises the DP4ER specifications, which is the objective of the D1.1, and determines the platform’s architecture. The development of the modules will continue during the next stages of the project, executed by the corresponding ENSNARE WPs.

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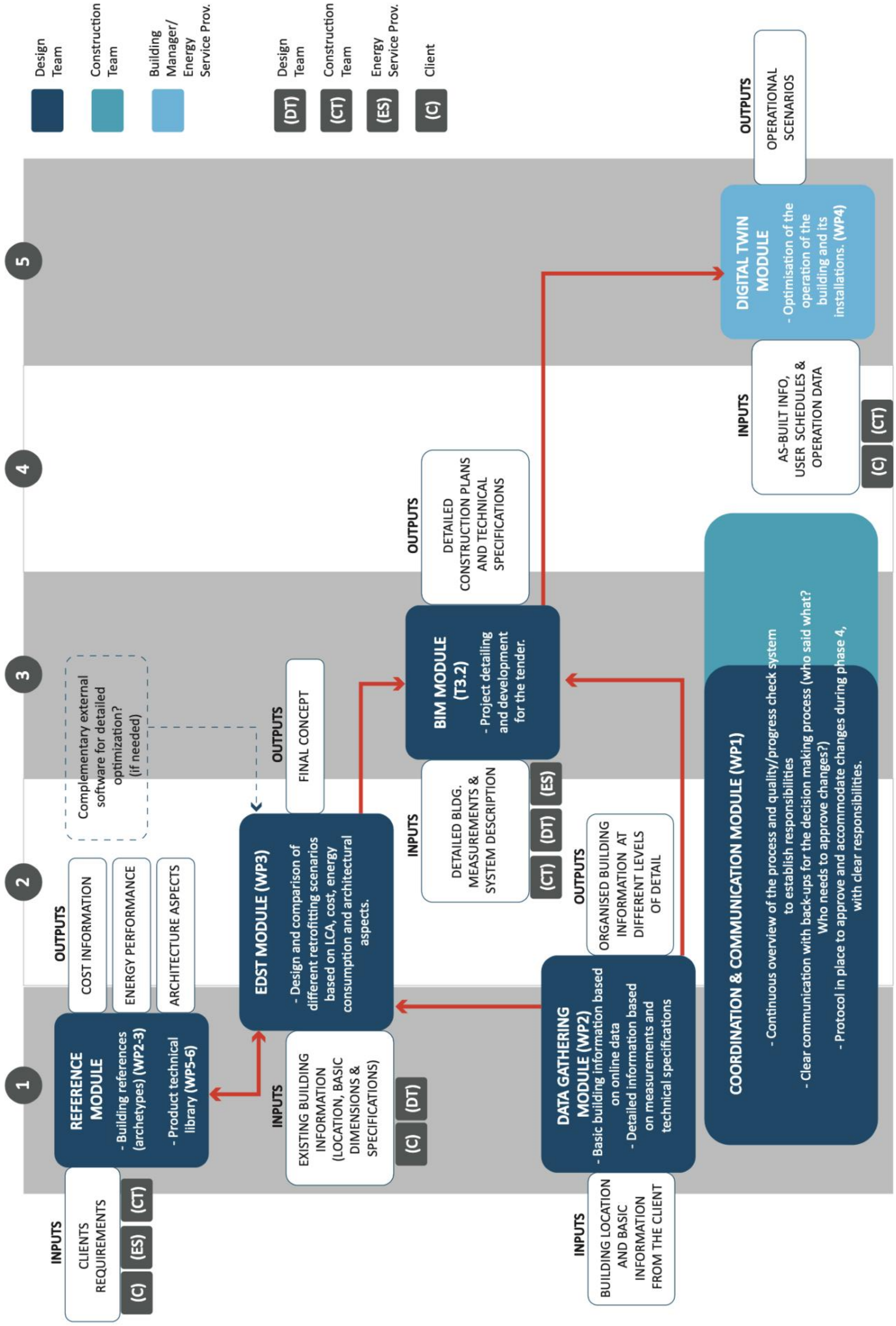

Figure 8.1. Map of the workflow in the context of ENSNARE

8.1. Reference module

The reference module will provide energy and cost calculations using simplified building archetypes, at the initial phases of the project (Phase 1 and 2, as shown in Figure 8.1). Besides, this module should provide basic information to the client about regulations, standards, constrains and incentives to establish what they are allowed to do in terms of building renovation according to their local guidelines and protocols. The responsible for the module (Design team) should guide the client through the technical possibilities available in the platform. The boundary conditions, such as the budget and the energy label/performance to be achieved, are essential to determine. This module might have a divulgation or marketing use enabling NZEB renovations, as it might present clients with renovation technologies that they might not have considered initially.

Such simplified calculations might be carried out using the Early Decision Support Tool (EDST) module (which is described below). When developing the design of the software architecture (Tasks 1.2 and 3.2), it will be evaluated whether the use of simplified archetypes is necessary or the EDST module can perform a fast, more accurate simulation of a simplified building in a specific climate condition.

The reference module and the EDST module will integrate a technical library of renovation solutions and products. Initially, these will be sourced from the ENSNARE consortium from the products developed in WP5 and WP6. Each of these solutions will have:

- A characterisation of energy performance
- Associated costs (e.g., €/kW) for investment and maintenance & operation
- Associated Greenhouse Gases (GHG) emissions (for production and installation) for the environmental LCA

This will enable the creation of a technical library (catalogue) of energy renovation solutions that can be exploited by the reference module and the EDST module. These solutions will include:

- Envelope insulation modules
- Multifunctional windows
- Building-integrated solar thermal collector modules
- Building-integrated photovoltaic modules
- Building-integrated Photovoltaic/Thermal (PV/T) hybrid modules

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- Heat pumps
- Thermal storage batteries

The reference module can be understood, and perhaps implemented, as an early iteration of the Early Decision Support Tool (EDST) module. The simulation engine and technical library of solutions will be common by both. The output of the early simulations will be stored within the ENSNARE platform and can form the basis of further detailed simulations to be performed with the EDST module.

8.2. Building data gathering module

The building data acquisition module consists of collecting and processing the necessary information of the building to design the prefabricated elements and devices, the necessary energy simulations, the off-site manufacturing, and the on-site installation. It is initiated in Phase 1, when information about the existing building is needed to make the first estimations, it extends to Phase 2 and links to modules in later phases, as shown in Figure 8.1. The building data gathering module consists of different stages, which correspond to the level of detail the renovation phases require.

First, during Phase 1, the "Data acquirer and processer" performs its activity only by using online information and the assistance of the building owner or client. In this phase, a non-detailed Building Information Model is created. This initial model will be used for a cost estimation of the works to be achieved. The building owner, especially on the first point, should provide several pictures of the building and a description of it.

On the second stage of the module the "Data acquirer and processer" visits the building and places both, the targets and the "Matching Kit" (data processing system that permits an accurate Building Information Model). This accurate BIM will be used for determining the energy needs of the building and the shape of the prefabricated elements. During this phase, the stakeholder in charge of the platform will execute a technical visit of the project and the model could be complemented with additional information. Finally, it is important to establish that this phase starts when a contract has been signed with the client.

The main outputs of this module provide the level of detail for an initial BIM module and a Computer-Aided Manufacturing (CAM) module that will be used by the other modules in the next phases, and it will help to evaluate the compatibility with different building components and products. Additionally, with the data described before, the manufacturer and the installer would have enough information to build

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the prefabricated elements. In principle, the libraries created by the manufacturer would be adjusted automatically to the building's geometry.

8.3. Early Decision Support Tool module

The main objective of the Early Decision Support Tool (EDST) module is to support the renovation project in its early design phases, so Phase 1 and 2, by proposing and assessing potential renovation solution kits. It will be designed to address the main bottlenecks identified in this early design stages, as described in D3.1 ENSNARE EDST Specifications.

The EDST will be designed as a simplified tool enabling its use in different devices and by users with different levels of expertise. The module will consist of a combination of submodules, such as the front end for input of information and presentation of the results, renovation scenarios generation, energy simulation, LCA and LCC.

The EDST module will be used by the design team for the initial exploration of solutions, but it is intended as a design tool for the comparison of design alternatives. Those design alternatives can be accessible for the client team at the appropriate level of detail. Architects and building engineering consultants have been identified as the primary users of this module, as they have the greatest expertise and knowledge to pilot the building renovation process. These agents could make use of the EDST to explore the implications of different solution kits (in terms of comfort, cost, energy consumption, etc.) to inform and enhance the design of the renovation project. The use cases of the EDST are described in greater detail in D3.1 ENSNARE EDST Specifications.

To achieve that, the EDST will be designed to be operated with a scalable complexity of information. It should allow a preliminary simulation with very few inputs (from the client or a designer that has not yet visited the building), but when more accurate information is available, this could be exploited to enhance the precision of the simulations. The EDST module might have different input modes for each user type (e.g., client or expert designer) or might have a common input screen that allows different levels of detail to facilitate use (e.g., providing default values and/or the possibility to edit 'advanced' settings).

As shown in Figure 8.1, the EDST utilises inputs from the reference and data gathering modules. The output provided by the EDST module will be fed into the BIM module of the platform. This could be further edited by other modules, for example the reference module, and/or forwarded to other modules or software for more detailed design or more advanced building energy simulation.

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8.4. BIM module

The Building Information Model (BIM) module has the objective to provide a detailed model of the existing building and the renovation measures, including all the information that are needed to proceed with the tender of the project. It will be generated by the Design team at the end of Phase 2 or beginning of Phase 3, after the optimization and finalization of the renovation solution, with the use of the EDST (Figure 8.1). The construction team and subcontractors should also have access to this module, to provide inputs and utilize the outputs.

Apart from defining the building's geometry and characteristics, the BIM will be the link between the data acquisition and processing of the building, the EDST and the digital twin (Figure 8.1). To this end, it will make available the detailed building data from the Data Acquisition in WP2. This BIM will be generated (semi) automatically with the information gathered in WP2, without the need of additional actions by the consultants and contractors Furthermore, it will include information about the renovation solution, so that the suppliers can know the specifications their products should follow to reach the required performance.

8.5. Coordination and communication module

The coordination and communication module aims at establishing a digital communication protocol when the decision-making process is presented and approved by all the parties (with special emphasis in the client). This module will be an informative tool where critical aspects are shown and they have to be approved by all the stakeholders to be able to access the new phase or stage of the renovation process, generating agreement files and backup.

This module will allow the design team or the manager of the platform to provide a continuous overview of the process and to guarantee that every decision made has been approved and accepted from all the parties, therefore, avoiding future disagreements.

This module will be available during the whole renovation process, as indicated in figure 8.1, to guarantee the quality and enable the progress of the project while providing clear responsibilities within the teams. The client and/or the design team will receive a summary of the phase/stage with the established agreements.

The module will provide all the information of the project, including logistics, technical responsibilities, changes in the budget/costs, timings on production, deliveries, regulations, etc. Additionally, it will show different levels of information to different stakeholders which will be assigned by the platform manager (design team).

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8.6. Digital twin module

This module will create a digital twin of the building, allowing for performance analysis, optimisation, and active control of systems during the operational phase. Once the Digital twin is in function the client/owner of the project will be the main user of the platform (figure 7.2). It is introduced at later phases of the project and its utilisation begins after the renovation execution and handover. However, it builds on information developed in the previous modules, as shown in Figure 8.1. The digital twin combines physics enabled simulations and data from real and virtual sensors to create a dynamic virtual representation of the building. The resulting digital asset can optimise the performance of the building beyond that of traditional systems, using machine learning to fill data gaps, check for anomalies and predict future performance.

To create the calibrated operational model, building information, energy consumption data and weather data are required as inputs. The building geometry can be imported from existing modules, described before or from existing compatible 3D models.

Information about building systems, schedules and equipment will also be collected from pilot leaders through a building data checklist. Where information is unavailable, assumptions will be made. The model will be calibrated such that the simulated energy matches that measured by the metering system.

The module will provide a calibrated digital twin for the building, with data stored in the data management platform and displayed through building-level dashboards. This will allow for continuous monitoring of the building performance and evaluation against design targets, establishing user behaviour patterns related with energy consumption and performance of the building after renovation.

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9. Conclusions

Aforementioned, the main goal of the ENSNARE project is to boost the implementation of NZEB renovation packages in Europe, with a focus on residential buildings providing a clear structure and access to a wide range of technologies. To accomplish this objective several specifications were defined. This report presents the development and the DP4ER Specifications.

Based on the analysis executed after following the steps proposed in the methodology described in Section 2, it can be determined that the platform's specifications consist of the module's definitions, their implementation, their interaction during the different phases, and the identification of the responsible technical user of the platform.

To define the specifications and to structure the data that will be handled at different stages of the renovation workflow, an analytical method has been adopted (Section 2) and deployed in the different activities and standardization of the information which helped to orientate the process to define the specifications. The methodological structure was executed in three steps:

a. Exploration: of current renovation workflow (Sections 3, 4 and 5)

b. Experts' interaction: questionnaire and workshop (Sections 6 and 7)

c. Elaboration: DP4ER Modules and workflow (Section 8)

The elaboration resulted in six modules that comprise the Digital Platform. The different modules are defined as separate tools, and they are applied in the different phases of the renovation process, as presented in Figure 8.1. Their output can also extend in next stages, to make the workflow more efficient. The technical user of the module corresponds with the targeted uses of the respective phases, as explained in Figure 7.1

The following modules are defined as the Digital Platform's tools:

1. Reference module: provides energy and cost calculations from simplified building archetypes. Besides, this module should provide basic information to the client about regulations, standards, constraints, as well as a technical library (catalogue) of energy renovation solutions.

2. Building data gathering module: collects and processes the necessary information of the building to design the prefabricated elements and devices, the required energy simulations, the off-site manufacturing, and the on-site installation.

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3. Early Decision Support Tool module: proposes and assesses potential renovation solution kits.

4. BIM module: creates a model for the construction and technical specifications.

5. Coordination and communication module: establishes a digital communication protocol when the decision-making process is presented and approved by all the parties.

6. Digital twin module: creates a digital twin of the building, allowing for performance analysis, optimisation, and active control of systems during the operational phase.

The Digital Platform is aimed at providing stakeholders with a clear structure and access to a wide range of technologies for deep renovation of buildings. It supports all stages of the renovation process, from early decision making and data acquisition to the manufacturing, construction works, and the operation and maintenance of the implemented system. The DP4ER specifications, as the main outcome of this D1.1 report, will be the starting point to develop the ENSNARE project objectives. On the one hand, the platform's architecture defines, which the next tasks of WP1 will develop and validate; on the other hand, the Digital Platform specification determine the development of the rest of the digital solutions (WP2, WP3 and WP4) as well as the specific components (WP5 and WP6). Finally and, once a beta version of the tool is available, this will be tested and validated using the pilot buildings (WP7) as reference.

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11. APPENDIX

11.1. Appendix 1: Overview of existing research projects

No.	Projects	Inf. Platform	Aim	Target	Input Data	Output Data	Phase	Web - Platform - Programs	ENSNARE Partners
1	**Hit2Gap**	Software Open source platform	Data acquisition	Energy service companies (ESCOs) Building managers (owner, users) Building engineering consultants	Building and services description Monitoring data / sensors	Maintenance data	Phase 4	https://hit2gap.eu https://bemserver.com	NOBATEK
2	**BIM4Ren**	Software (BIM)	*digitisation *Renovation scenario modelling	Architectural Designers Building engineering consultants Building managers (owner, users)	Building and services description Questionnaires	BIM model, existing bldg. And post-renovation Quality check reports	Phase 2 Phase 4	https://bim4ren.eu	NOBATEK TECNALIA
3	**Built2Spec**	Software (Toolbox)	Quality check digital toolbox	Architectural Designers Building engineering consultants Construction companies	Building and services description	Quality check reports	Phase 2 Phase 4	http://built2spec.eu	NOBATEK

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No.	Projects	Inf. Platform	Aim	Target	Input Data	Output Data	Phase	Web - Platform - Programs	ENSNARE Partners
4	**Energy Matching**	Software (Toolbox / BIM)	Optimised Building energy with Skin solutions	Architectural Designers Building engineering consultants Construction companies Energy service companies (ESCOs Building managers (owner, users) Real Estate developers / investors Governmental bodies	3D models Properties of the envelope Weather data	BIM model, existing bldg. And post-renovation Quality check reports Energy production data / self-sufficiency	Phase 2 Phase 3	https://platform.energymatching.eu/ https://www.energymatching.eu/	R2M
5	**BERTIM**	*Consultant *Informative	* High energy performance prefabricated modules with high energy efficiency * An innovative holistic renovation process methodology * Affordable business opportunity	Building managers (owner, users) Construction companies	Building and services description	BIM model, existing bldg. and post-renovation Energy production data / self-sufficiency	Phase 2 Phase 3	http://bertim.eu/index.php?lang=en	TEC/TUM
6	**EUReCA platform: Energy Urban Resistance Capacitance Approach**		Evaluation of Urban Energy Demand at District level, Evaluation of energy conservation measures at district level	Architectural Designers	Properties of the envelope Building and services description HVAC systems Weather data	Energy production data / self-sufficiency	Phase 3	https://github.com/BETALAB-team/EUReCA https://research.dii.unipd.it/betalab/facilities-tools/simulation-models/ https://www.sciencedirect.com/science/article/pii/S0960148121005085	UNIPD

No.	Projects	Inf. Platform	Aim	Target	Input Data	Output Data	Phase	Web - Platform - Programs	ENSNARE Partners
7	**Creation of One Click LCA Platform for calculating life cycle emissions**	*Software platform *Informative	*Software and solutions in the construction, calculate environmental impacts * Faster eco-design, greener building	Construction companies Architectural Designers Building managers (owner, users) Real Estate developers / investors System supplier	Materials Performance of components Properties of the envelope	LCA results & emissions Energy demands & consumption data	Phase 1 Phase 2 Phase 3 Phase 4 Phase 5	www.oneclicklca.com	BIONOVA
8	**StepUP**	*Software open source platform *Informative *Consultant	*Renovation reliable *Performance gap to <10% *Time on site to <40% *Renovation investments	Building managers (owner, users) Architectural Designers Construction companies	Design scenarios Monitoring data / sensors	Energy demands & consumption data Energy production data / self-sufficiency		https://www.stepup-project.eu/	ABUD
9	**NewTREND**	*Consultant *Informative	*Integrated Design Methodology *Retrofit design towards the next generation of energy-efficient and sustainable buildings and districts	Architectural Designers Energy service companies (ESCOs)	Pictures Building and services description 3D models	BIM model, existing bldg. And post-renovation Renovation scenarios comparisons	Phase 1 Phase 2 Phase 3 Phase 5	http://newtrend-project.eu/	ABUD
10	**Retrokit**	*Software platform *Training *Consultant	*Increase efficiency and quality in home retrofit projects *Reduce carbon footprint *Improve well-being of their tenants	Building managers (owner, users) Energy service companies (ESCOs) Construction companies		Energy demands & consumption data Energy production data / self-sufficiency	Phase 2 Phase 3	https://retrokit.eu/	TEC

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No.	Projects	Inf. Platform	Aim	Target	Input Data	Output Data	Phase	Web - Platform - Programs	ENSNARE Partners
11	**BRESAER**	Software Tools	*Technological combinations and energy saving estimates *System potential by geolocation *Support of envelope components installation *Full monitoring and control system in charge of gathering data from the sensoring network	Architectural Designers System supplier Construction companies	Building and services description Monitoring data / sensors Archetype buildings	BIM model, existing bldg. And post-renovation Maintenance data Energy demands & consumption data	Phase 2 Phase 3 Phase 4 Phase 5	http://www.bresaer.eu/	TEC
12	**Zero-Plus**	*Consultant *Informative	* Housing that achieves renewable energy and energy savings targets set by the recipient at the lowest possible cost; * Clear information on the trade-offs between cost and performance; * Ensure that the recipient has all the information they need for optimal, cost-effective maintenance.	Architectural Designers Building engineering consultants Construction companies Construction companies Building engineering consultants	Monitoring data / sensors Archetype buildings Performance of components	Energy demands & consumption data Energy production data / self-sufficiency LCA results & emissions	Phase 1 Phase 2 Phase 3 Phase 4 Phase 5 Phase 3 Phase 4	http://www.zeroplus.org/index.php	TUM

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No.	Projects	Inf. Platform	Aim	Target	Input Data	Output Data	Phase	Web - Platform - Programs	ENSNARE Partners
13	**HEAT4COOL**	*Consultant *Informative	*Building retrofitting * Retrofitting design planner tool * Integration of Heating and Cooling solution * Wastewater heat recovery * Self-Correcting Intelligent Building Energy Management System (SCI-BEMS) * Demonstrate and validate the market oriented heating and cooling solution	System supplier Architectural Designers Building managers (owner, users) Construction companies Building engineering consultants			Phase 2 Phase 3 Phase 4	https://www.heat4cool.eu/	TEC, BAL
14	**BASAJAUN**	*Consultant *Informative	*Rural development *Sustainable wood construction *Digitalization and innovation	Construction companies Architectural Designers System supplier		LCA results & emissions BIM models, existing bldg. And post-renovation Maintenance data	Phase 2 Phase 4	https://basajaun-horizon.eu/#basajaun	TEC
15	**SunHorizon**	*Consultant *Informative	*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 (owner, users) Energy service companies (ESCOs)			Phase 2 Phase 5	https://www.sunhorizon-project.eu/	IES

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No.	Projects	Inf. Platform	Aim	Target	Input Data	Output Data	Phase	Web - Platform - Programs	ENSNARE Partners
16	**RenoZEB**	*Consultant *Informative *Training *Collaboration platform web	*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		Maintenance data BIM models, existing bldg. And post-renovation LCA results & emissions	Phase 2 Phase 4	https://renozeb.eu/	TEC
17	**BIPVBOOST**	*Consultant *Informative *Training *Commercialisation of the products	*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			Phase 2 Phase 4	https://bipvboost.eu/	TEC

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11.2. Appendix 2: Questionnaire template

ENSNARE Experts' questionnaire

You have been invited to take part in a research study. Before deciding on participation, please read the text below carefully. The text is divided in two sections: (a) INFORMATION SHEET and (b) INFORMED CONSENT FORM

a. INFORMATION SHEET

This study is part of the ENSNARE research project, funded by the European Commission, and running from 01/01/2021 to 31/01/2025. The ENSNARE project aims to provide a systemic methodology combining products, systems and solutions that will contribute to boost the adoption of novel and advanced technologies in the renovation sector looking to achieve high energy efficiency standards for buildings.

The main goal of the ENSNARE project is to boost the implementation of NZEB renovation packages in Europe, with a focus on residential buildings. To accomplish this objective, the project develops two key structures: an envelope mesh and a digital platform that interconnect all building components. The envelope mesh is fully modular and facilitates the mechanical assembly and interconnection of all components and energy/data networks. The digital platform is aimed at providing stakeholders with a clear structure and access to a wide range of technologies for deep renovation of buildings. It supports all stages of the renovation process, from early decision making and data acquisition to the manufacturing, construction works, and the operation and maintenance of the implemented system.

One of the project tasks deals with the definition of a digital-based platform that enables this novel methodology, covering the overall renovation process. To design this platform a specific activity will be performed to collect information that will support the identification and selection of specifications for the ENSNARE Digital Platform for Envelope Retrofitting (DP4ER). This collection of information is aimed to be focused under different user's perspectives considering also barriers and opportunities to develop the referred platform (DP4ER).

Research method:

The research method will be the following anonymous online questionnaire. Filling in the questionnaire will take approximately 15 minutes.

Results of the study:

The results of the study will be integrated in the project report "D1.1 – ENSNARE DP4ER specifications". As the questionnaires are anonymous, and the responses will be aggregated into conclusions, no personal data will be processed nor published. This will be a public report that will be available in the project website.

Risks, discomforts or disadvantages versus benefits of participating:

No particular risks, discomforts or disadvantages are foreseen for participants in this study. On the other hand, with your answers you would be providing an important contribution to research and development in the area of building renovation and envelope retrofitting. In any case, your participation shall be entirely voluntary, and you have the right to refuse to participate and to withdraw participation or data at any time (before giving consent of after) without any consequences.

Organisation responsible and contact researcher(s):

Delft University of Technology (TUDelft) is the organisation responsible of the study within project ENSNARE. For any questions or clarifications that you may need, feel free to ask the contact researcher(s), Alejandro Prieto (A.I.PrietoHoces@tudelft.nl) or Thaleia Konstantinou (T.Konstantinou@tudelft.nl)

b. INFORMED CONSENT FORM

Information / data needed to perform the study:

The anonymous information that you may provide will be exclusively used to perform the study. The study is expected to conclude by 31.07.2021.

Anonymity of the information provided:

Information on anonymisation procedures, during the study including possible publications, and organisational and technical procedures put in place. For example:

• The questionnaire has been designed to avoid obtaining personal data from you

• Only generalized, broad categories are used regarding age, gender or type of occupation

• The researchers will perform an anonymity check before merging the anonymous information resulting from participants answers and delete, pseudonymise, generalise or categorise any datum that could lead to indirect identification of the participant or any other third person

• The informed consent form only includes a tick-box to give consent

• Privacy in publications: the anonymisation procedure assures also that only anonymised information and conclusions will be used in any possible publication arising from the research study or containing references to it.

• All information provided by participants will be deleted at the date of completion of the study.

1. **I hereby declare:**

• I am 18 years or older and I am competent to provide consent;

• I have been fully informed about the aims and purposes of this study and the conditions of participation;

• I understand that there is no compulsion to participate and that, if I choose to participate, I may at any stage withdraw my participation.

I. General information about the respondent and the organization they represent

2. What is the core business of the organization you are affiliated to?

- *Architectural Design*
- *Building Engineering consultancy*
- *Construction*
- *Building product development / Building system supply*
- *Energy services*
- *Building / Real Estate Management*
- *Real Estate development / investment*
- *Government (local or national)*
- *Other________________*

3. What is the size of the organization?

- *Micro (1-9 employees)*
- *Small (10-49 employees)*
- *Medium (50-249 employees)*
- *Large (>250 employees)*

4. Which is the country where your organization is based?

- *Austria*
- *Belgium*
- *Bulgaria*
- *Croatia*
- *Cyprus*
- *Czechia*
- *Denmark*
- *Estonia*
- *Finland*
- *France*
- *Germany*
- *Greece*
- *Hungary*
- *Iceland*
- *Ireland*
- *Italy*
- *Latvia*
- *Lithuania*
- *Luxembourg*
- *Malta*
- *Netherlands*
- *Norway*
- *Poland*
- *Portugal*
- *Romania*

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- *Slovakia*
- *Slovenia*
- *Spain*
- *Sweden*
- *United Kingdom*
- *Other: ___________________________*

5. **What is your position within the organization?**
    - *Main Manager / Director*
    - *Middle / Intermediate manager*
    - *Technician*
    - *Administrative*
    - *Other: ___________________________*

6. **How many years of experience do you have in the field?**
    - *<5 years*
    - *Between 5 and 10 years*
    - *More than 10 years*

II. General experience about the building renovation process

for the next questions, please refer to the following scheme detailing the main five phases of the renovation process:

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. Set-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, handover	Post-occupancy evaluation / optimization loops

7. **Which stakeholders are involved in PHASE 1: Pre-project?**
    (Please tick every stakeholder involved in this phase)
    - *Architects*
    - *Engineering consultants*
    - *Contractors*
    - *System suppliers*
    - *Energy solution providers*
    - *Building managers and/or users*
    - *Building owners*
    - *Real Estate Developers and/or investors*
    - *Government bodies / policy actors*
    - *Other: ___________________________*

8. **Which stakeholders are involved in PHASE 2: Concept design?**
    (Please tick every stakeholder involved in this phase)
    - *Architects*

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- *Engineering consultants*
- *Contractors*
- *System suppliers*
- *Energy solution providers*
- *Building managers and/or users*
- *Building owners*
- *Real Estate Developers and/or investors*
- *Government bodies / policy actors*
- *Other: ___________________________*

9. Which stakeholders are involved in PHASE 3: Final design?
(Please tick every stakeholder involved in this phase)

- *Architects*
- *Engineering consultants*
- *Contractors*
- *System suppliers*
- *Energy solution providers*
- *Building managers and/or users*
- *Building owners*
- *Real Estate Developers and/or investors*
- *Government bodies / policy actors*
- *Other: ___________________________*

10. Which stakeholders are involved in PHASE 4: Execution and handover?
(Please tick every stakeholder involved in this phase)

- *Architects*
- *Engineering consultants*
- *Contractors*
- *System suppliers*
- *Energy solution providers*
- *Building managers and/or users*
- *Building owners*
- *Real Estate Developers and/or investors*
- *Government bodies / policy actors*
- *Other: ___________________________*

11. Which stakeholders are involved in PHASE 5: Post-construction?
(Please tick every stakeholder involved in this phase)

- *Architects*
- *Engineering consultants*
- *Contractors*
- *System suppliers*
- *Energy solution providers*
- *Building managers and/or users*
- *Building owners*
- *Real Estate Developers and/or investors*
- *Government bodies / policy actors*
- *Other: ___________________________*

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12. In which phase of the renovation do you see the involvement of your organization <u>more significant</u>?

- *Phase 1 – Pre-project*
- *Phase 2 – Concept design*
- *Phase 3 – Final design*
- *Phase 4 – Execution and handover*
- *Phase 5 – Post-construction*

13. The renovation of existing buildings involves multiple technical/technological, social, cultural and financial factors. Based on your experience, How do POTENTIAL CLIENTS perceive the following factors in terms of their relevance?

Please judge all parameters in terms of their relevance (according to the clients' perception)

	No relevant --	-	+/-	+	*Highly relevant* ++
Aesthetic aspects					
Cultural aspects					
Social aspects					
Health aspects					
Comfort aspects					
Economic aspects (cost, ROI)					
Energy consumption					
Intrinsic value					
Environmental awareness					
Warm glow (personal satisfaction)					
Planning & timeframe					

14. Can you think of other highly relevant factors FOR POTENTIAL CLIENTS? If so, please state them below.

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____

15. How relevant are these factors FOR YOU, based on your personal experience with renovation projects?

Please judge all parameters in terms of their relevance (according to your own experience)

	No relevant --	-	+/-	+	*Highly relevant* ++
Aesthetic aspects					
Cultural aspects					
Social aspects					
Health aspects					
Comfort aspects					
Economic aspects (cost, ROI)					
Energy consumption					
Intrinsic value					
Environmental awareness					
Warm glow (personal satisfaction)					
Planning & timeframe					

16. Can you think of other highly relevant factors FOR YOU? If so, please state them below.

____

III. Specific experience: involvement in the different renovation phases

****for the next groups of questions, please refer to the Renovation phases scheme. This section is aimed at <u>YOUR specific expertise</u> within the renovation process, so please reply the following questions based on your role throughout the***

process. If you are not involved in one of the phases, please skip that phase and continue with the next one.

Phase 1 – Pre-project

Phase description: Defines the need for the project, the problems, the ambition. Sets the design team up

17.Are you (personally) involved in this phase?

- *Yes*
- *No*

18.What are your main tasks within this phase?

(You may choose more than one, but please check a maximum of three tasks)

- *Setting objective and criteria*
- *Diagnosis of existing condition*
- *Definition of client requirements*
- *Cost initial estimate*
- *Selection design team*
- *Others: ____*

19. With which stakeholders do you collaborate during this phase?

(you may choose more than one)

- *Architectural Designers*
- *Building Engineering consultants*
- *Construction companies*
- *System suppliers / manufacturers*
- *Energy solution providers*
- *Building managers & occupants*
- *Building owners*
- *Real Estate developers / investors*
- *Governmental bodies / policy actors*
- *Others________________*

20.What type of input do YOU REQUIRE FROM OTHERS, to perform your tasks <u>during this phase</u>?

(You may choose more than one)

- *Description of the existing building / building archetypes*
- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*
- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*

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- *Cost information of building components and systems*
- *Others: ____________________________*

21.What type of input are YOU REQUIRED TO PROVIDE TO OTHERS during the phase?

(you may choose more than one)

- *Description of the existing building / building archetypes*
- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*
- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ____________________________*

22.What is(are) the main result(s)/output(s) that you generate during this phase?

(You may choose more than one, but please check a maximum of three)

- *BIM/3D models of existing and/or post-renovation building*
- *Envelope retrofitting design scenarios*
- *Energy demands/consumption data*
- *On-site energy generation data*
- *Indoor comfort data*
- *Cost information, budget and/or cash-flow of the intervention*
- *Quality check reports*
- *Data for maintenance and the building energy management system*
- *Life cycle analysis (LCA) and Life Cycle Cost Analysis (LCCA)*
- *Greenhouse Gas Emissions and/or Global Warming Potential (GWP) data*
- *Installation & Assembly guidelines*
- *Logistics & planning guidelines*
- *Others: ____________________________*

23.In your experience, what are the main bottlenecks that would need to be solved in order to increase the efficiency of the renovation process DURING PHASE 1 - Pre-project?

____

Phase 2 – Concept design

Phase description: Identification and comparison of strategy, interventions, design principles

24.Are you (personally) involved in this phase?

- *Yes*

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- *No*

25.What are your main tasks within this phase?

(You may choose more than one, but please check a maximum of three tasks)

- *Identification of renovation measures*
- *Decision on industrialised components design concept*
- *Assessment and optimisation*
- *Preparation of permit applications*
- *Others: ____*

26. With which stakeholders do you collaborate during this phase?

(you may choose more than one)

- *Architectural Designers*
- *Building Engineering consultants*
- *Construction companies*
- *System suppliers / manufacturers*
- *Energy solution providers*
- *Building managers & occupants*
- *Building owners*
- *Real Estate developers / investors*
- *Governmental bodies / policy actors*
- *Others_________________*

27.What type of input do YOU REQUIRE FROM OTHERS, to perform your tasks <u>during this phase</u>?

(You may choose more than one)

- *Description of the existing building / building archetypes*
- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*
- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ______________________________*

28.What type of input are YOU REQUIRED TO PROVIDE TO OTHERS during the phase?

(you may choose more than one)

- *Description of the existing building / building archetypes*
- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*

- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ____________________________*

29. What is(are) the main result(s)/output(s) that you generate during this phase?

(You may choose more than one, but please check a maximum of three)

- *BIM/3D models of existing and/or post-renovation building*
- *Envelope retrofitting design scenarios*
- *Energy demands/consumption data*
- *On-site energy generation data*
- *Indoor comfort data*
- *Cost information, budget and/or cash-flow of the intervention*
- *Quality check reports*
- *Data for maintenance and the building energy management system*
- *Life cycle analysis (LCA) and Life Cycle Cost Analysis (LCCA)*
- *Greenhouse Gas Emissions and/or Global Warming Potential (GWP) data*
- *Installation & Assembly guidelines*
- *Logistics & planning guidelines*
- *Others: ____________________________*

30. During the EARLY DESIGN STAGE, do you use any decision support tool for assessing thermal performance, energy efficiency and/or return of investment?

Please select only the tools used at EARLY DESIGN STAGE. Multiple options can be selected.

- *No specific tools: early design is based on first principles and/or prescriptive guidance*
- *Simplified or own calculation tools (e.g. Excel spreadsheets)*
- *Plug-ins for design software (SketchUp, Revit, Rhino, etc.)*
- *National tools for verification of energy efficiency (EPBD) regulations*
- *Tools of third-party standards (Passivhaus-PHPP, Minergie, etc.)*
- *Dynamic Building Energy Simulation tools (IES VE, IDA ICE, EnergyPlus, etc.)*
- *Other: ______________*

31. If it applies, which energy assessment tool(s) do you use at the EARLY DESIGN STAGE?

Please mention the specific tool(s) that you commonly use.

____

32. In your experience, what are the main bottlenecks that would need to be solved in order to increase the efficiency of the renovation process DURING PHASE 2 – Concept design?

____

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Phase 3 – Final design
Phase description: Tender, specification of products, engineering of components

33. Are you (personally) involved in this phase?
- *Yes*
- *No*

34. What are your main tasks within this phase?
(You may choose more than one, but please check a maximum of three tasks)
- *Detailed design for industrialised renovation*
- *Survey of existing building*
- *Engineering of the components*
- *Tender and products specification*
- *Others: ____*

35. With which stakeholders do you collaborate during this phase?
(you may choose more than one)
- *Architectural Designers*
- *Building Engineering consultants*
- *Construction companies*
- *System suppliers / manufacturers*
- *Energy solution providers*
- *Building managers & occupants*
- *Building owners*
- *Real Estate developers / investors*
- *Governmental bodies / policy actors*
- *Others________________*

36. What type of input do YOU REQUIRE FROM OTHERS, to perform your tasks <u>during this phase</u>?
(You may choose more than one)
- *Description of the existing building / building archetypes*
- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*
- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ____________________________*

37. What type of input are YOU REQUIRED TO PROVIDE TO OTHERS during the phase?

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(you may choose more than one)

- *Description of the existing building / building archetypes*
- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*
- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ____________________________*

38. What is(are) the main result(s)/output(s) that you generate during this phase?

(You may choose more than one, but please check a maximum of three)

- *BIM/3D models of existing and/or post-renovation building*
- *Envelope retrofitting design scenarios*
- *Energy demands/consumption data*
- *On-site energy generation data*
- *Indoor comfort data*
- *Cost information, budget and/or cash-flow of the intervention*
- *Quality check reports*
- *Data for maintenance and the building energy management system*
- *Life cycle analysis (LCA) and Life Cycle Cost Analysis (LCCA)*
- *Greenhouse Gas Emissions and/or Global Warming Potential (GWP) data*
- *Installation & Assembly guidelines*
- *Logistics & planning guidelines*
- *Others: ____________________________*

39. At the TENDER STAGE, once the design is finished, do you use any tool for assessing its energy performance?

Please select only the tools used at the TENDER STAGE. Multiple options can be selected.

- *No specific tools: early design is based on first principles and/or prescriptive guidance*
- *Simplified or own calculation tools (e.g. Excel spreadsheets)*
- *Plug-ins for design software (SketchUp, Revit, Rhino, etc.)*
- *National tools for verification of energy efficiency (EPBD) regulations*
- *Tools of third-party standards (Passivhaus-PHPP, Minergie, etc.)*
- *Dynamic Building Energy Simulation tools (IES VE, IDA ICE, EnergyPlus, etc.)*
- *Other: ______________*

40. If it applies, which energy assessment tool(s) do you use at the TENDER STAGE?

Please mention the specific tool(s) that you commonly use.

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41. In your experience, what are the main bottlenecks that would need to be solved in order to increase the efficiency of the renovation process DURING PHASE 3 – Final design?

____

Phase 3 – Execution and handover

Phase description: Manufacturing, assembly off-site and on site, handover

42. Are you (personally) involved in this phase?

- o *Yes*
- o *No*

43. What are your main tasks within this phase?

(You may choose more than one, but please check a maximum of three tasks)

- o *Manufacturing*
- o *Transport*
- o *Mounting*
- o *Site Construction*
- o *Construction quality control*
- o *Handover*
- o *Others:* ____

44. With which stakeholders do you collaborate during this phase?

(you may choose more than one)

- o *Architectural Designers*
- o *Building Engineering consultants*
- o *Construction companies*
- o *System suppliers / manufacturers*
- o *Energy solution providers*
- o *Building managers & occupants*
- o *Building owners*
- o *Real Estate developers / investors*
- o *Governmental bodies / policy actors*
- o *Others*_______________

45. What type of input do YOU REQUIRE FROM OTHERS, to perform your tasks <u>during this phase</u>?

(You may choose more than one)

- o *Description of the existing building / building archetypes*
- o *Pictures from the existing building and services*
- o *2D plans and/or 3D models of the building*
- o *Description of building services (existing and/or new)*
- o *Properties of the envelope and its components (existing and/or new)*
- o *Building retrofitting scenarios*

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- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ____________________________*

46. What type of input are YOU REQUIRED TO PROVIDE TO OTHERS during the phase?

(you may choose more than one)

- *Description of the existing building / building archetypes*
- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*
- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ____________________________*

47. What is(are) the main result(s)/output(s) that you generate during this phase?

(You may choose more than one, but please check a maximum of three)

- *BIM/3D models of existing and/or post-renovation building*
- *Envelope retrofitting design scenarios*
- *Energy demands/consumption data*
- *On-site energy generation data*
- *Indoor comfort data*
- *Cost information, budget and/or cash-flow of the intervention*
- *Quality check reports*
- *Data for maintenance and the building energy management system*
- *Life cycle analysis (LCA) and Life Cycle Cost Analysis (LCCA)*
- *Greenhouse Gas Emissions and/or Global Warming Potential (GWP) data*
- *Installation & Assembly guidelines*
- *Logistics & planning guidelines*
- *Others: ____________________________*

48. In your experience, what are the main bottlenecks that would need to be solved in order to increase the efficiency of the renovation process DURING PHASE 4 – Execution and handover?

____

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Phase 5 – Post-construction
Phase description: Post-occupancy evaluation / optimization loops

49.Are you (personally) involved in this phase?
- o *Yes*
- o *No*

50.What are your main tasks within this phase?
(You may choose more than one, but please check a maximum of three tasks)
- o *Building operation optimisation*
- o *Monitoring*
- o *Post occupancy*
- o *Others:* ____

51. With which stakeholders do you collaborate during this phase?
(you may choose more than one)
- o *Architectural Designers*
- o *Building Engineering consultants*
- o *Construction companies*
- o *System suppliers / manufacturers*
- o *Energy solution providers*
- o *Building managers & occupants*
- o *Building owners*
- o *Real Estate developers / investors*
- o *Governmental bodies / policy actors*
- o *Others*________________

52.What type of input do YOU REQUIRE FROM OTHERS, to perform your tasks <u>during this phase</u>?
(You may choose more than one)
- o *Description of the existing building / building archetypes*
- o *Pictures from the existing building and services*
- o *2D plans and/or 3D models of the building*
- o *Description of building services (existing and/or new)*
- o *Properties of the envelope and its components (existing and/or new)*
- o *Building retrofitting scenarios*
- o *Monitoring data from on-site sensors & description of sensors*
- o *Energy consumption information*
- o *Weather and location data*
- o *User schedules*
- o *Data from occupant's questionnaires*
- o *Cost information of building components and systems*
- o *Others:* ___________________________

53.What type of input are YOU REQUIRED TO PROVIDE TO OTHERS during the phase?
(you may choose more than one)
- o *Description of the existing building / building archetypes*

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- *Pictures from the existing building and services*
- *2D plans and/or 3D models of the building*
- *Description of building services (existing and/or new)*
- *Properties of the envelope and its components (existing and/or new)*
- *Building retrofitting scenarios*
- *Monitoring data from on-site sensors & description of sensors*
- *Energy consumption information*
- *Weather and location data*
- *User schedules*
- *Data from occupant's questionnaires*
- *Cost information of building components and systems*
- *Others: ____________________________*

54.What is(are) the main result(s)/output(s) that you generate during this phase?

(You may choose more than one, but please check a maximum of three)

- *BIM/3D models of existing and/or post-renovation building*
- *Envelope retrofitting design scenarios*
- *Energy demands/consumption data*
- *On-site energy generation data*
- *Indoor comfort data*
- *Cost information, budget and/or cash-flow of the intervention*
- *Quality check reports*
- *Data for maintenance and the building energy management system*
- *Life cycle analysis (LCA) and Life Cycle Cost Analysis (LCCA)*
- *Greenhouse Gas Emissions and/or Global Warming Potential (GWP) data*
- *Installation & Assembly guidelines*
- *Logistics & planning guidelines*
- *Others: ____________________________*

55.In your experience, what are the main bottlenecks that would need to be solved in order to increase the efficiency of the renovation process DURING PHASE 5 – Post-construction?

____

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11.3. Appendix 3: Material of the workshop

Figure AP3.1: Elaboration of platform framework (Round 1): Groups 1,2, 3 and 4

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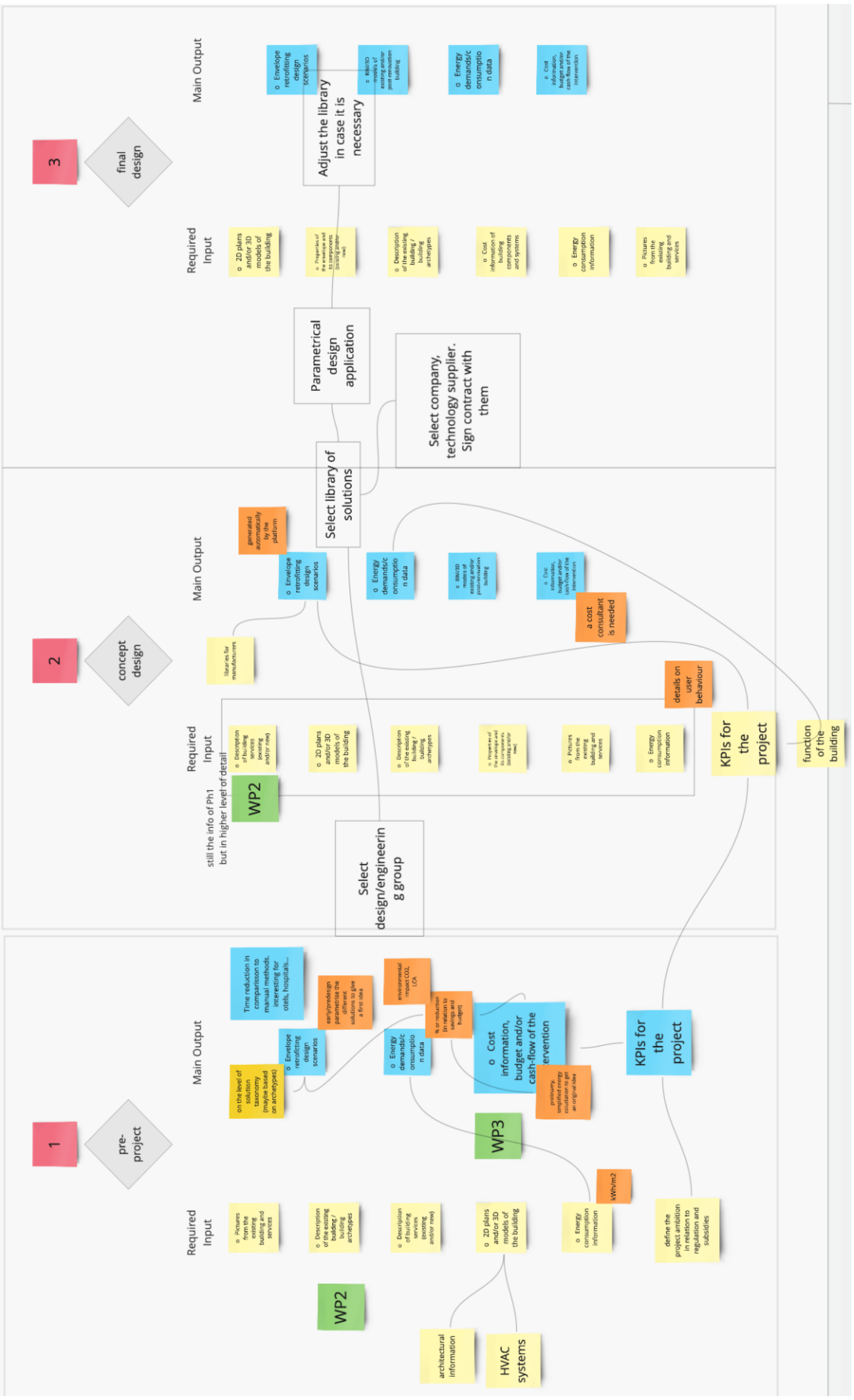

Figure AP3.3: Design Platform Workflow (Round 2): Digital Components, to specified the format and the level of detail.

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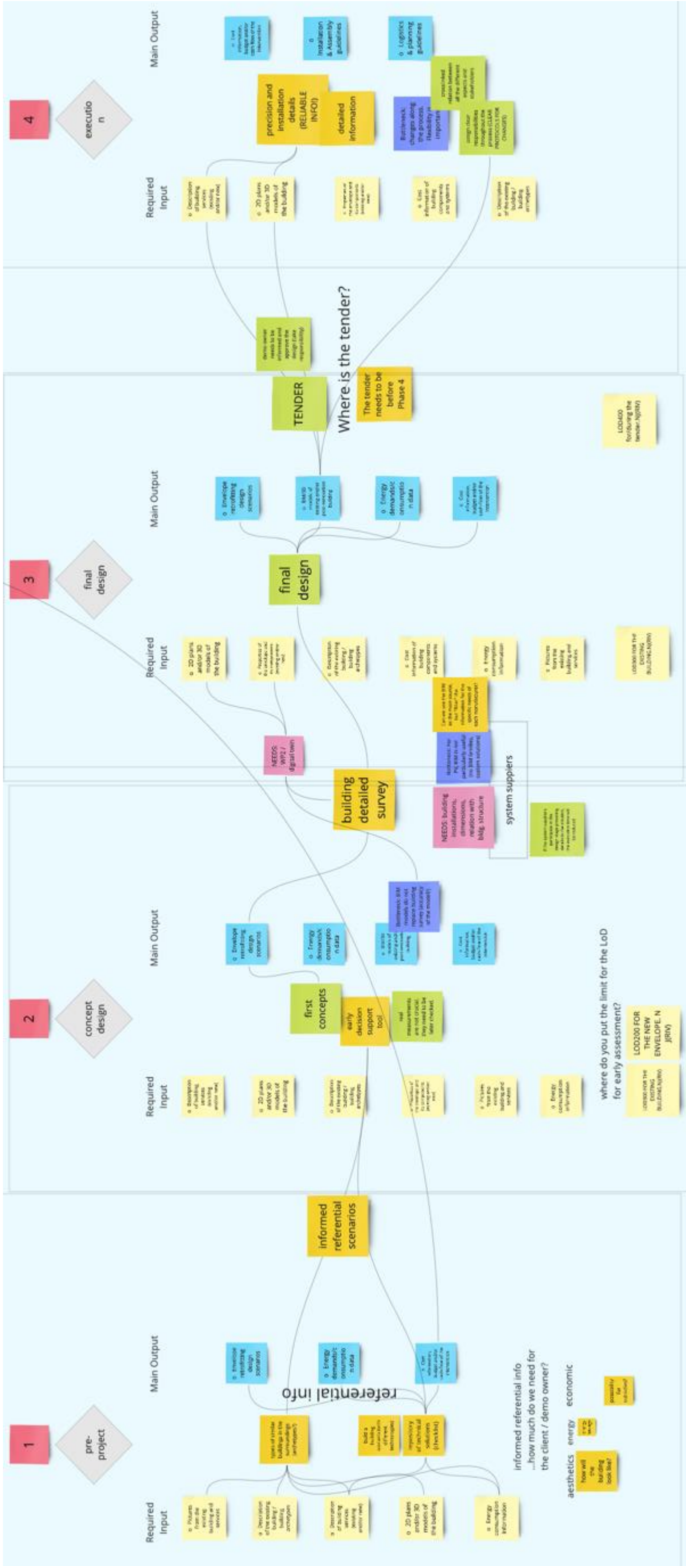

Figure AP3.4: Design Platform Workflow (Round 2): Physical Components, to specified the format and the level of detail.

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