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ENSNARE - ENvelope meSh aNd digitAl framework for building Renovation

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0.1	05/07/21	First version	CIVI	Overall structure, Chapter 1, 3, 4 and 5
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Executive Summary

The ENSNARE project aims at increasing and supporting the implementation of nZEB renovation packages through the development of an industrialized envelope mesh and of a digital platform that will interconnect all ENSNARE's solutions.

The report represents the first step of the development of the early decision support tool (EDST). The tool will be an integral part and a key component of the digital platform since it will provide different types of users with information and context for a wide range of energy renovation technologies. The EDST will be developed within the WP3 taking into account what has been defined in WP1. The tool will elaborate the inputs provided by the users and as a result, it will present tailored solution packages combining the technologies that are best suited to the specific case considered.

The report is subdivided in the following sections:

- *Introduction. T*he introduction will present the ENSNARE project, as well as its aims and goals. In addition, the purpose of this report and its relation with the other activities of the WP3 will be further clarified in the following paragraphs.
- *Aim and objectives*. This section will introduce the purpose of the EDST and it will present the subdivision of the different stages of the project identified within WP1, the results of the questionnaire developed in WP1-Task 1.1, and described in D1.1 ENSNARE DP4ER Specifications [n].
- *Literature review.* Building energy retrofitting has been widely debated in the literature since it is recognized as a complex process involving different decision variables and aspects such as technical, technological, social, cultural and environmental aspects. This section will analyse the methodologies evaluating different retrofit strategies based on their effects; their contribution on energy consumption modelling and retrofit strategies impacts on CO_2 emissions reduction. In addition, the section will briefly summarize the main Early Decision Support Tools developed in different H2020 projects.

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- *Identification of the stakeholders and use cases.* Based on the results of WP1 questionnaire, a number of different roles involved in the renovation process were identified and classified. Such roles have been classified in four main *stakeholder groups* and presented in this section. Moreover, four main EDST use cases have been identified and are described in this section.

- *Early Decision Support Tool structure.* The EDTS will provide the different users with tailored solution packages combining the technologies that are best suited to the specific case considered. This section has been subdivided in three parts which correspond with the different stages of the decision-making process (namely, the Investigative Phase, the Design Phase and the Decision Phase).

- *Product requirements.* This section will summarize the product requirements and functionalities that have been identified.

- *Conclusions.* The main findings of the report and the overall process/methodology will be synthetized.

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List of Abbreviations

API	Application Programming Interface
BIM	Building Information Modelling
BIPV	Building-integrated photovoltaics
CDE	Carbon dioxide emission reduction
CO2	Carbon dioxide
D3.1	Deliverable 3.1
DP4ER	Digital Platform for Envelope Retrofitting
DSCR	Debt service coverage ratio
DSS	Decision support system
DST	Decision support tool
EDST	Early Decision Support Tool
EPBD	Energy Performance of Buildings Directive
ESCO	Energy service company
FSA	Formative Scenario Analysis
GHG	Greenhouse gas
H2020	Horizon 2020
HER	Home energy retrofit
HVAC	Heating, ventilation and air conditioning
IFC	Industry Foundation Classes
IRR	Internal rate of return
KPI	Key Performance Indicator

LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCOE	Levelized cost of energy
NPV	Net present value
NZEB	Nearly zero-energy building
O&M	Operation & maintenance
PB	Payback
PES	Primary energy saving
PHPP	Passive House Planning Package
PV	Photovoltaic
PV/T	Photovoltaic/thermal
T3.1	Task 3.1
WP	Work package

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1. Introduction

1.1. Context. ENSNARE project, WP3 and T3.1

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 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. 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 the present document is related to the definition and development of a significant component of the platform; the Early Decision Support Tool (EDST) and, specifically, as part of the WP3 Decision support toolkit. The objective of this first Work Package of the project is to define the EDST 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, aiming to achieve a contract with that client. This tool will be a web-based tool that, by means of simplified calculations, simulates energy, cost and comfort indicators.

The main outcome of this WP3 will be the development of a complete toolkit, that is later integrated into the project's digital platform, named as "Early Decision Support Tool" (EDST). 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.

1.2. Purpose

The information included in this Deliverable 3.1 is the result of the works carried out in Task 3.*1 ENSNARE EDST specifications* where the main objective is to define the specifications and requirements of the Early Decision Support Tool.

The information required to define these specifications is related with the expected outputs that the tool will provide in terms of time, costs, and comfort estimations, according to the information that is introduced as inputs, that describes the building to be retrofitted. The tool will consider alternative solutions to renovate the building, taking into account the main benefits of the technologies developed within ENSNARE, with the main goal to upgrade the building up to a highly energy efficient concept. For this purpose, a multi-objective optimization process will be developed with a life cycle perspective, calculating KPIs for embodied and operational energy, associated greenhouse gas emissions, comfort and health impacts, and economic viability.

The definition of this tool is designed to be able to develop the simulations with general information about the scenario to be calculated such as, the building/facade characteristics, the type of use, number of dwellings, climate characteristics of the zone and orientation, insulation level, material and components characteristics, typology of its heating systems, etc. In this way, preliminary estimations for the intervention can be obtained.

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,

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combination, and visualization of the data at the early decision stage of the retrofitting process.

1.3. Relation with other activities

This deliverable collects outputs from Task 3.1 and is regarded as the first step for the development of the EDST. The results will mostly feed into other activities and deliverables within WP1:

- *Task 3.2 ENSNARE EDST architectural design - Data 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 EDST.
- *Task 3.3 ENSNARE EDST algorithm definition and implementation:* This task will effectively develop the toolkit, based on the architecture and specifications as defined in previous tasks.
- *Task 3.4 ENSNARE EDST visualization platform:* A specific development of the tool will deal with the necessities and alternatives for visualizing the results, allowing the user to evaluate alternatives. A specific data visualization application will be developed for this purpose.
- *Task 3.5. ENSNARE EDST validation:* Once the complete toolkit 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.

Apart from the specific research aimed to materialize the EDST in WP3, 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 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, covered by this EDST, is the initial phase of the complete

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renovation process. In order to give an overall support to the user, beyond this initial stage, the project will develop a Digital Platform for envelope retrofitting (DP4ER) in WP1, defining workflows and data interchange in different stages of the renovation process. The EDST will be one of the components integrated into the DP4ER platform.

As described for the EDST, 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 main components that will be considered for renovating the buildings are the ones se defined, manufactured, and tested as parts of the research in WP5 *Industrialized and modular envelope system* and WP6 *Energy harvesting and storage modules*.

Finally, and once the main solutions developed in ENSNARE are validated, these 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.

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. The outcomes from the EDST, will be an initial representation of the building that will be later improved to achieve the Digital Twin model.

For properly orienting all those activities and WPs, the specifications identified and considered in this initial stage in T3.1, are necessary and relevant to define the specifications of all these components before starting to develop them.

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2. Aim and objectives

The aim of this report is to define the specifications and requirements for the early decision support tool (EDST) 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 client to obtain the contract. The partial objectives to achieved are:

- To *define a web-based tool* to allow its use from different platforms and hardware.
- To allow the users *to obtain energy, cost and comfort results* matching web-based information and simplified simulation tools.
- To be able to *provide a first version of the building* with envelope retrofit proposals.
- To obtain an *initial budget of the entire process.*

The specifications and requirements of this EDST will be defined taking into account time and cost savings, available information, requirements from the client and the companies involved.

This early decision support tool will be developed as an integral part of the digital platform to provide an initial result in terms of price and energy characteristics using a supply chain point of view. In the terminology set in WP1 five building renovation project stages have been identified (Figure 1): Pre-project (Phase 1); Concept design (Phase 2), Final design (phase 3), Execution and handover (Phase 4) and Post-construction (Phase 5). In order to establish the different use cases of the EDST, an identification of the relevant user types (stakeholders) and an analysis of their common and specific requirements have been performed. Information has been drawn from within the ENSNARE Consortium, through the questionnaire developed in WP1-Task 1.1, and described in Section 12 of D1.1 *ENSNARE DP4ER Specifications [n]*.

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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

Figure 1. Building renovation phases defined in WP1

During the development of this questionnaire, specific questions addressing the EDST requirements were included. The sample of this questionnaire is comprised of 42 answers obtained from different institutions within the Consortium, covering a wide range of European countries and business types. The answers suggest that EDST should mainly focus on the early stages of project design, where the scope is being set and design alternatives might be proposed and evaluated with limited data available (mostly from online sources). In the terminology set in D1.1 ENSNARE DP4ER Specifications, the relevant project stages for the EDST would be phase 1 (pre-project) and partially phase 2 (concept design). In the conclusions from the questionnaire, the stakeholders involved in the pre-project stage (phase 1) were the client team (building owners, users and managers, developers, investors or public bodies), which would initiate the project, and the design team (architects, engineering consultants). For the subsequent concept design stage (phase 2), the design team would be the leading agent and the involvement from the client team would be reduced. Results from the questionnaire indicated that other agents (contractors, system suppliers, energy solution providers) are mostly involved at construction stage and do not have a leading role in the early stages that are relevant for the EDST. However, they can provide valuable information that the client and design team can exploit at these early stages to achieve a faster, more efficient and economic renovation process.

The bottlenecks identified by the participants of the questionnaire have been analysed. The EDST should provide an attempt to solve, improve or address the relevant bottlenecks in phases 1 and 2. These are assessed in the tables below.

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Bottleneck identified in Task 1.1	Potential improvement by EDST
Limited information about the existing building (construction, envelope, structure)	Possibility of running the EDST with limited information about the building (e.g. extracted from online sources)
Limited energy consumption data	Possibility of estimating energy consumption from default 'use scenarios' (user schedules, set point and set back temperatures)
Unclear definition of renovation objective and KPIs	Clear KPIs provided (e.g. energy, comfort, cost) and multi-criteria assessment performed based on the choices selected by the user
Unclear design proposals at this stage hinder the clients' decision-making process	The EDST could generate and suggest 'renovation kits' so that the client can ask them to be incorporated into the design proposals
Bureaucracy	Some information on national regulations could be incorporated into the EDST. However, these are often local and rapidly changing
Limited involvement and participation of specialists (mostly developer and owner)	Key information of renovation solutions (requirements, characterisation of energy performance) included within EDST database
Not enough depth in the technical project to come up with reliable cost estimations	LCC module and cost information on the renovation technologies incorporated to EDST for a reliable preliminary cost estimation
Lack of interested clients and governmental incentives	The EDST could be accessible to clients as a marketing or divulgation tool, so that they can perform a simplified calculation and learn about renovation kits that could suit their building

Table 1. Bottlenecks identified for Phase 1 (Pre-project) and relevance for EDST

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Bottleneck identified in Task 1.1	Potential improvement by EDST
Limited information about the existing building and its use.	Possibility of running the EDST with limited information about the building (e.g. extracted from online sources). Possibly, a second iteration could be performed when onsite information is available (e.g. from survey or scan)
Not enough information about building products	The platform will include a database with performance and cost information for the renovation solutions.
Bureaucracy	Outside the scope of the EDST
Unclear overview of national or local normative that need to be followed	
Limited availability of project information (drawings & specifications)	Communication and responsibility issues are outside the scope of the EDST. The platform should enhance the communication through the use of a common information model
Communication issues and limited information exchange between stakeholders	
Unclear client-designer communication	
Low involvement and response time from system suppliers	
Unclear responsibilities of the local architects and other stakeholders	
Unreliable assessment and optimisation of different design options	The uncertainty and unreliability of energy/cost predictions (and thus their optimisation) is mostly unrelated to model or software issues. It has been primarily attributed to the lack of reliable input information on the building and the usage patterns. The aim of the EDST will be to simplify the building model and enhance and support the information input.
Uncertain building energy performance predictions	
Unreliable cost predictions of energy services	
Lack of skilled professionals to assemble a consortium	In the future, the platform could include a database of professionals. At the moment this is outside the current scope of the ENSNARE project.

Table 2. Bottlenecks identified for Phase 2 (Concept design) and relevance for EDST

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Finally, specific questions were included as part of the Task 1.1 questionnaire for the stakeholders involved at the early design stage and the tender stage.

The answers are broken down in the table below and, despite the limited sample, are indicative of the current situation. Concerning the early design stage (which is the main aim of the EDST), some interesting findings are listed below:

- National verification tools for EPBD regulations appear to have very limited use.
- Five respondents make use of dynamic energy simulation tools which require significant expertise.
- Many stakeholders use simplified calculation tools or no tools at all. The development of an user-friendly EDST could be useful in involving these agents.

	At early design stage	At tender stage
Dynamic Building Energy Simulation tools (IES VE, IDA ICE, EnergyPlus, etc.)	5	0
Tools of third-party standards (Passivhaus-PHPP, Minergie, etc.)	1	1
Plug-ins for design software (SketchUp, Revit, Rhino, etc.)	7	2
National tools for verification of energy efficiency (EPBD) regulations	3	1
Simplified or own calculation tools (e.g. Excel spreadsheets)	7	5
No specific tools: design based on first principles and/or prescriptive guidance	7	6

Table 3. Use of energy simulation tools as declared by stakeholders that answered the WP1 questionnaire

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3. Literature review

Buildings energy retrofit is a complex process involving a great number of decision variables and issues related not only to technical and technological aspects, but also to environmental, social and cultural aspects. This topic is widely debated in literature. This section analyses the literature submissions to explore:

- Methodologies to evaluate different retrofit strategies according to their economic, environmental and social effects (e.g., multi-criteria analysis, life cycle costing and assessment, econometric models, etc.).
- Contributions on energy consumption modelling and evaluation involving BIM.
- Impacts of retrofit strategies on CO2 emission reduction.

A large number of decision support systems were identified covering different systems for the refurbishment of buildings. An analysis of these systems is summarised by (Ferreira et al., 2016)[1] in Figure 2.

Reference DM Tool	Building[a]	Environment	Economy	Methods				
				General methods	Energy &/ or CO2	Purely economic methods	LCA methods	Sustainable assessment methods
Gorgolewski et al. (1995)	R	Energy Consumption	LCC			X		
TOBUS (Balaras, 2002; Caccavelli and Gurgerli,2002;Flourentzou et al.,2002)	S	Energy Consumption; Environmental comfort	Investment costs		X			
Caldas and Norford, 2002	R&S	Energy Consumption			X			
XENIOS(Dascalaki and Balaras,2004)	S	Energy Consumption; Renewable energies; Solid waste	Investment costs; Estimated payback time					X

[1] Ferreira, J., Pinheiro M.D., de Brito.,J., 2016. Refurbishment decision support tools review—Energy and life cycle as key aspects to sustainable refurbishment projects. Energy Policy62,1453–1460.

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EPIQR (Jaggs and Palmer, 2000; Parc Scientifique de L'EPFL-PSE, 2004)	R	Energy Consumption (and Renewable energies); IEQ	Investment costs		X			
Alanne, 2004	R&S	Client definition	Investment costs; Operational costs			X		
INVESTIMMO (Balaras et al., 2005a-Balaras et al., 2005b)	R	Energy Consumption; Building's state of physical/functional deterioration; Estimated future deterioration; Water consumption; (Air and CO_2; Liquid effluents; Solid waste	Investment costs; Operational costs; Long term effectiveness of investments					X
Kaklauskas et al., 2005	R&S	Client definition	Client definition	X				
Pushkar et al., 2005	R&S	LCA					X	
Wang et al., 2005	R&S	LCA	LCC				X	
Zhang et al., 2006	R&S	LCA; Materials and resources; Safety; Convenience					X	
Kaklauskas et al., 2007	R&S	Client definition	Client definition	X				
Martinaitis et al., 2007	R	Energy Consumption; Building's state of physical/functional deterioration;	CCE; LCC			X		
Zavadskas and Antucheviciene, 2007	S	Client definition	Client definition	X				
Diakaki et al., 2008	R&S	Energy Consumption	Investment costs		X			
Juan et al., 2009b	R	Site assessment; Use functionality; Convenience; IEQ; Energy Consumption; Water consumption; Health	Investment costs; Net Present Value; LCC					X
Lee et al., 2009	R&S	LCA; Energy Consumption; CO_2					X	
Diakaki et al., 2010	R&S	Energy Consumption; CO_2	Investment costs		X			
Juan et al., 2010	S	Site assessment; IEQ; Energy Consumption; Water consumption; Materials and resources	Investment costs					X
Li et al., 2010	R&S	LCA					X	
Liu et al., 2010	S	Energy Consumption; Air emissions	Net Present Value; Investment costs; Operational costs		X			
Thompson and Bank, 2010	R&S	Client definition	Client definition	X				
Wang and Zeng, 2010	S	Safety		X				
Crawford et al., 2010-Crawford et al., 2011	R	Energy Consumption (in LCA)					X	
MultiOpt: Chantrelle et al., 2011	R&S	Energy Consumption; Life Cycle CO2emissions; Thermal comfort	Investment costs		X			

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Mora et al., 2011	R&S	LCA; Estimated future deterioration					X	
Tsai et al., 2011	R&S	Energy Consumption; Life Cycle CO2emissions	LCC				X	
MOGA (Wright and Loosemore, 2011)	R&S	Energy Consumption; Thermal comfort	Investment costs; Operational costs			X		
Saporito et al., 2011	S	Energy Consumption			X			
Srinivasan et al., 2012	R&S	Energy Consumption (in LCA)					X	

Legend: [a] R= Residential, S = Service, R&S = Residential and Service.

Figure 2. Comparison of different decision support tools for refurbishment

These figures show that the development of decision-making tools to support the refurbishment of buildings has generated very diverse methods with distinct purposes, involving different assessment criteria that are generally defined on the design stage. Energy and CO2 efficiency are the issues most often analysed and interpreted as key factors in promoting sustainable refurbishment projects.

There has been an evolution from single-objective to multi-objective algorithms using methods like fuzzy set theory, genetic algorithms and simple weighted-sum algorithms.

Studies have been carried out on criteria weighting (an area always affected by subjectivity), focusing on the use of AHP and willingness to pay. As in other areas these studies are characterised by diverse uncertainties.

The analysis of the different authors allowed to identify the following needs for DSS for building retrofitting:

- The evolution from an operational perspective to a life cycle approach has indicated LCA as the most promising tool to exploit in future to assess environmental aspects, so it could be introduced into new decision-making models.
- LCC could supplement LCA by enabling an economic analysis.
- Since local databases of solutions are essential, especially in relation to the relevant life cycle costs, precise work is needed in this area.
- Tools can also be thought of in a regional perspective, since problems may be different from climate to climate, from economy to economy.

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- Instruments that adopt a stochastic rather than a deterministic perspective should be considered more closely in order to reduce uncertainty.

Several EDSTs have been developed in different H2020 projects. In the following section, a set of EDST have been analysed and categorized according to the following characteristics:

- Aim of the project and of the tool.
- Target users of the tool.
- Inputs required.
- Outputs of the analysis.

Name	Aim	Target Users	Input	Output	Link
BemServer	BEMServer is an open source platform which aim is to ease the deployment of energy management software in monitored buildings. The platform has been developed within the HIT2GAP project will develop a new generation of building monitoring and control tools based on advanced data treatment techniques.	End user (energy managers, building owners, facility managers, ESCOs and energy efficiency consultants) Module developers Contributors (developers)			https://bemserver.com
BIM4Ren	The project develops a range of tools for data acquisition linked to the BIM value chain. The BIM4Ren digital ecosystem will be accessible via a web-based One-Stop Access Platform. The Platform offers different tools for the: - Data acquisition - Strategic planning - Data driven design - Data management - Support	The tool is primarily targeted to architects and building designers.		Depending on each user profile, best practice examples from a dedicated database and links to the different tools and services (from top grade to entry level) will be provided on differentiated access schemes underpinned by different business models.	https://bim4ren.eu/#objectives

Name	Aim	Target Users	Input	Output	Link
Built2Spec	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. The Built2Spec tools will be integrated in a virtual, BIM-enabled, cloud-based construction management platform which is structured to mirror the most advanced integrated design and delivery frameworks for the building sector.			The platform will provide installation guidelines, shared design specifications, 3D models and relevant information on regulatory frameworks. In addition, workers and their supervisors will have access to workflow, status, training information and product data sheets through their tablets. During the project, this platform will be integrated into the operations of small and medium-sized enterprise (SME) contractors, large construction firms and end user clients directly within the consortium and work program activities, assuring systematic and scientific performance measures, feedback and powerful exploitation.	https://built2spec-project.eu/tools/virtual-construction-management-platform/
Energy Matching	EnergyMatching Tool (EM Tool), has been developed to optimize the positions and capacity of the BIPV system and the capacity of the associated electric storage.	The tool is primarily targeted to architects and building designers.	- Measuring geometry - Context geometry - Weather data - Techno-economic parameters	- NPV over-time - Expected payback time - Electricity production and consumption - Self-consumption and self-sufficiency	https://platform.energymatching.eu/ https://www.energymatching.eu/ EnergyMatching (EM) Tool for optimization

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Name	Aim	Target Users	Input	Output	Link
				- Expected LCOE and LCOEself - Specific equivalent CO2 emissions	of RES harvesting at building and district scale
EUReCA platform: Energy Urban Resistance Capacitance Approach	The Energy Urban Resistance Capacitance Approach provides an efficient and reliable Urban Building Energy Modelling platform, aiming at simulating and predicting cities and urban areas energy consumption.		- Weather data - Building envelopes data - Operational schedules of occupancy, appliances, temperature, humidity setpoints, HVAC usage for different end-uses - Plant models	The tool exploits a bottom-up modelling methodology, creating simple and useful dynamic building energy models.	https://research.dii.unipd.it/betalab/
NewTREND	NewTREND aims to improve the energy efficiency of the existing building stock and to improve the current renovation rate by developing a new participatory integrated design methodology aimed at the energy retrofit of buildings. The aim of this tool is to: - Evaluate potential energy efficiency solutions; - Guide the decision makers in the selection of the best energy retrofitting strategy.	All people involved in the retrofit project including end users, architects, energy consultants.			http://newtrend-project.eu/ http://newtrend-project.eu/wp-content/uploads/2015/11/Booklet-7-Tools-of-NEWTREND.pdf
Retrokit	RetroKit enables housing sector decision makers and advisors to identify retrofit opportunities and develop retrofit strategies.	- Housing providers - Energy retrofit professionals - Sustainable energy communities	- Baseline energy performance - Energy use and expenditure - Carbon savings - BER rating - End users' objectives	- Energy retrofit action plan, - Identifies packages energy conservation measures with budget estimates - Funding opportunities - Work plan	https://retrokit.eu/ https://www.retrokit.eu/products-and-services/#training

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Name	Aim	Target Users	Input	Output	Link
		- Researchers/policy makers			
BRES-DES	BRES-DES is a web-based estimation tool and it has been developed with the BRESAER project. The tool is intended to be used in the early design stages of an energy retrofit using the BRESAER system for building envelopes.	It helps designers consider the potential energy savings from using the BRESAER energy retrofit system.	- Climate - Solution priorities - Specify basic dimensions - Specification of surfaces to be used - General geometry - Common usage of envelopes and systems - Equipment capacity	Output organization by level of detail: Building, Floor and Façade The main objective of the tool is obtaining design suggestions and energy saving estimates	http://www.bresaer.eu/tools/ http://www.bresaer.eu/wp-content/themes/bresaer/tools-pdf/BRESAER_Manual_BRES-DES_TEI.pdf
HEAT4COOL	Heat4Cool aims at identifying a set of solution to optimise the integration of a set of rehabilitation systems. The project also provides an EDST. The main functionality of this tool is to suggest and simulate alternatives for the renovation of domestic heating and/or cooling systems.	Five user families were defined: - Administrator - Architect - Manufacturer - Retrofitting solution provider - Resident The tool does not have different versions for each, but allows different levels of detail in the inputs to facilitate use (providing default values and the possibility to edit advanced inputs)	- Building type (detached, semi-detached, terrace, apartment…) - Age (construction date) - Location - Dimensions (simplified geometry, width x length x number of storeys) - Orientation - Percentage of windows - Available area for solar collectors, technical equipment, etc. - Energy source (electricity, gas, coal…) - Heat generating device (boiler, heat pump…) - Emitter system (radiators, fan coils, underfloor heating…)	A results page showing: - A list of suggested renovation packages - A ranking of these packages based on multiple criteria (energy use, GHG emissions, cost, comfort) - Tables and graphs showing performance indicators for each page: energy use, renewable contribution, estimated energy cost, payback period, comfort deviation…) - Technical and regulatory info on each package	https://www.heat4cool.eu/ https://iopscience.iop.org/article/10.1088/1742-6596/1343/1/012128/pdf

Name	Aim	Target Users	Input	Output	Link
			- Storage system (no storage, tank…) - Cooling device (no cooling, heat pump…) - Number of occupants - Use schedule Optional: - U-values - Thermal bridge heat loss - Air infiltration - Type of ventilation system - Heat capacity of envelope and internal elements - Primary energy factors - Greenhouse gas emission factors - Fuel cost - Set point and set back temperatures		
IES Digital Twin suite (ICL)	The ICL is a platform that integrates different DST with aim to facilitate the planning, design and operation of energy efficient communities. The platform provides different levels of complexity of Digital Twins for decision making, from early decision to detailed analysis.	Key users include owners, designers, technical consultants.	For simplified analysis, core information may include: Building type, construction year/ type, condition, hours of use, location, orientation, fuel utilized, HVAC type/ efficiency, photographs/ plans/ sections/ elevations, monthly/ yearly energy consumption/ bills, construction/ building envelope information and U-values, existing improvements, fenestration,	Energy performance and decarbonisation metrics	https://www.iesve.com/icl

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Name	Aim	Target Users	Input	Output	Link
			floor/ footprint areas, adjacent building information (shading), occupancy, schedules, equipment, lighting, renewables, ventilation, infiltration.		
APM tool "REfurbishment decision making platform through advanced technologies for near Zero energy BUILDing renovation" (REZBUILD)	The tool connects the different actors involved in the reform process to obtain different scenarios depending on the inputs and requirements of each project. The tool allows to compare the different scenarios.	Owner, ESCO, engineering, architects, constructors, Real state.	Building model (BIM) and KIPs: Economical, social, comfort, energy. TO BE Building model (BIM) and KIPs: Economical, social, comfort, energy.		https://rezbuildproject.eu/
BIM SOLAR		Owner, ESCO, engineering, architects, constructors, Real estate	Building model (BIM) and KIPs: Economical, social, comfort, energy.	Decision support, feasibility studies, optimization for Building Applied and Integrated Photovoltaics 1. Cell, module, transparency: configurator for PV layouts, inverter and wiring 2. BIM prescription within the master project, expert collaboration in connected mode	http://www.bim-solar.com/en/bimsolar-4/

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Name	Aim	Target Users	Input	Output	Link
DesignBuilder	The creation of a building model, location, occupancy schedules and construction materials.	Designers, engineering consultants		Detailed sub-hourly information on energy consumption and demand, comfort etc.	https://designbuilder.co.uk//

Table 4. Characteristics of existing EDSTs

4. Identification of stakeholders and use cases

A number of different roles involved in the renovation process were identified and classified as part of Task 1.1. The questionnaire developed in WP1 was targeted to these business types. As part of the assessment process of the results, such roles were aggregated in four main *stakeholder groups*.

The objective of the EDST is to address the needs of these stakeholders in the early design process. To better identify and fulfil the specific requirements of each agent in the renovation process, *use cases* are proposed for the EDST. These use cases and their target stakeholders are identified in the table below.

Stakeholder group (WP1)	Classification		Business type (WP1)	EDST use case (WP3)
Design team	IU	2	Architectural design	Comparison of design alternatives
			Building engineering consultancy	
Client team	IU	1	Building owner	Initial exploration of solutions
			Building manager	
			Building user	
			Real estate manager	
			Real estate developer	
			Government	
Other	EU	12	Research and development	Research
			Other consultancy	
Construction team	EU	1	Construction	Provision of information to database
			Building product development	
			Building system supplier	
Energy services	EU	2	Energy service provider	

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Table 5. EDST use cases addressed to the business types and stakeholder groups identified in WP1 and classification

Four main EDST use cases have been identified and are described in more detail below.

- *Comparison of design alternatives*. The design team has been identified as the primary user of the EDST. Architects and building engineering consultants can use their expertise and knowledge of the building renovation process to gain the greatest benefit from the EDST.

Architects, engineers and consultants 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 EDST needs to perform an energy simulation, a life cycle assessment (LCA) and a life cycle costing (LCC) of these options. A multicriteria assessment that brings together all these analyses would be provided at the end of the process.

Design professionals might be aware of more detailed information than the general public (e.g. U-values of existing walls, glazing characteristics, etc.), so it would be useful if they could input this information where available.

- *Initial exploration of solutions.* An additional use of the EDST could be as a simplified tool for clients to explore the renovation potential of their building. Ideally, the EDST would highlight potential technologies that match the typology, use or climate of their building to encourage clients to attempt a NZEB renovation. This use would take place even before there is a design team or indeed any type of contract.

It is essential that the EDST is user friendly and supports the use by a user that does not have any specific expertise in building renovation or the construction process. With very few inputs (e.g. location, age of building, simplified geometry, number of storeys, use, etc.), the EDST would suggest default options that are most likely to be representative of the building, in order to perform simplified simulations that are not precise but are representative. At a later stage, if a design team gets involved, they could make a more accurate use of the tool for assessing design alternatives.

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This use is addressed by the reference module proposed in D1.1 *ENSNARE DP4ER Specifications*, which could either be a standalone module or included as a subset of the EDST module. This would be discussed when developing the software architecture of the ENSNARE platform and the EDST as part of the Tasks 1.2 and 3.2.

- *Research.* A secondary use of the EDST could be its application as a research or consultancy tool by public or private bodies. The implication of different renovation alternatives (in terms of energy, cost, emission reduction, etc.) over a representative or archetype building could be simulated. However, this is not the main aim or target of the EDST and its development will not be directed to fulfil this use.

- *Provision of information to database*. Suppliers of building products and energy services are not expected to use the EDST as a design aid. However, their involvement in providing information (energy usage, LCA, investment and maintenance cost) is critical for the usability of the EDST. From their perspective, the EDST can be a very useful marketing tool to inform clients about their products, to demonstrate their viability in renovating specific buildings in a given climate, and ultimately enhance their market share and improve the NZEB renovation rate.

In order to ensure privacy and be able to manage access to the tool and final reporting, users can be classified as follows

- According to involvement in the efficiency pathway: ***internal users (IU)*** are professionals directly involved in the retrofitting activity (design and construction team); ***external users (EU)*** are professionals not directly involved in the design, construction and realization activities (client team).

- According to reporting needs: ***class 1 (1)*** is for those who need only benchmark indicators that describe the behaviour of the renovated building; ***class 2*** **(2)** is for professionals who, in addition to benchmark indicators, need to identify and quantify energy efficiency measures.

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As part of the WP1 questionnaire, respondents were asked to rate the relevance of various factors that influence the renovation process: aesthetics, cultural, social, health, comfort, cost/economy, energy, intrinsic value, environmental, personal satisfaction, and planning and timeframe.

Respondents were asked to rate the relative importance of the above in two different ways: (1) their perception of the clients' judgment, and (2) their own judgment.

Four of these have been selected for analysis, as they could be measured by specific KPIs:

- Economic aspects (cost, return of investment): measured by return of investment.
- Comfort aspects: measured by indoor temperature range.
- Energy consumption: measured by non-renewable primary energy use.
- Environmental awareness: measured by greenhouse gas emissions.

The answers have been rated on a numeric scale from 1 to 5, where 1 is not relevant and 5 is highly relevant. The tables below show the average relevance attributed to each case.

	Economic	Comfort	Energy	Environmental
All	4.68	4.24	4.05	3.07
Clients	4.00	3.33	2.50	1.66
Designers	4.91	4.27	4.27	3.20

Table 6. Relevance (1-5) given by building renovation clients to each aspect (top row) according to each stakeholder group (left column)

	Economic	Comfort	Energy	Environmental
All	4.39	4.54	4.56	4.34
Clients	4.00	5.00	4.67	4.33
Designers	4.55	4.27	4.27	4.27

Table 7. Relevance (1-5) of each aspect (top row) attributed by each stakeholder group (left column)

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It is interesting to note that results diverged significantly: respondents tended to award more relevance to almost every item (except the economic aspect) than the relevance that they perceived from clients. The general approach of the construction market seems much better captured by the top table: perhaps respondents tend to be more sincere (inadvertently) when responding to the relevance that they *perceive from others* rather than their own. The clients' perception from other clients is particularly interesting, as it reflects the general ranking but in a more extreme way.

For private clients, the economic aspect (return of investment) would be the most relevant in making decisions, followed by comfort (improvement on indoor comfort). Energy consumption and environmental issues would not be perceived as highly relevant if not tied to associated cost.

Other agents (public bodies, designers, suppliers) seem to perceive a more balanced view among all aspects, but still agree with the general trend noted above.

The findings noted above could be useful for ranking KPIs in a multicriteria analysis within the EDST. In order to maximise usability, predefined 'weighting criteria' could be set for different user types. Additional features could also be added:

- Each user would get the results suited to their 'weighting criteria', but could also see results based on the point of view of other users.
- As an advanced feature, users could input their own weightings depending on their specific interest (maximising comfort or economic gain, minimising energy use or environmental damage).

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5. Early Decision Support Tool (EDST) structure

The EDST will perform a pre-feasibility analysis of different retrofit options, providing the various actors involved in a retrofit project with an overview of the economic and environmental impact of their choices and to allow a more conscious decision-making process. The conceptual scheme of the Early Decision Support Tool is represented in Figure 3, in which the three typical phases are highlighted, as in (Mattiussi et al., 2014)[2]:

- The *Investigative Phase* concerns data acquisition (characterization of the buildings, technologies and users).
- The *Design Phase* consists of the analysis performed through simulations.
- The *Decision Phase*. Having identified the technical feasible solutions from technical-economic and environmental perspective, the last step of the methodology involves the development of a decision-making model to assist with the final choice among the identified solution sets.

The first step is the definition (through the so-called Formative Scenario Analysis-FSA) of the list of alternative building scenarios to be evaluated. The considered scenarios are selected from a list of available technologies namely multifunctional windows, BIPV cladding module PV/T hybrid module, roll-bond solar collector, insulation module, heat pump and thermal storage. Technical features of each technology to be evaluated must be available, e.g. efficiency, technical limits and constraints (that determine its applicability). Their selection is driven by the desired indoor temperature, according to the compliance with some technical constraints specific to each technology. Economic features such as capacity-specific investment costs, but also O&M costs must be available for each of the considered technologies in order to allow the evaluation.

[2] A. Mattiussi, M. Rosano, P. Simeoni, A decision support system for sustainable energy supply combining multi-objective and multi-attribute analysis: an Australian case study. Decision Support System (2014), 10.1016/j.dss.2013.08.013

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Besides technical constraints for each considered technology, site-specific boundary conditions are also considered, e.g. the absence of determinate condition for installation determining the automatic exclusion from the DSS evaluation of the non-compliant scenarios. Finally, concerning the constraints imposed on the output of the multi-objective optimization model, mainly the compliance with some threshold value of economic indicators such as e.g. maximum payback time and minimum debt service coverage ratio (DSCR) can been imposed as a constraint of the developed model. Since the aim of the toolbox is to perform a sustainable pre-feasibility of home energy retrofit (HER), besides the economic objective functions, also the environmental (carbon dioxide emission minimization) and the energetic (primary energy consumption minimization) ones will be considered within the developed EDST.

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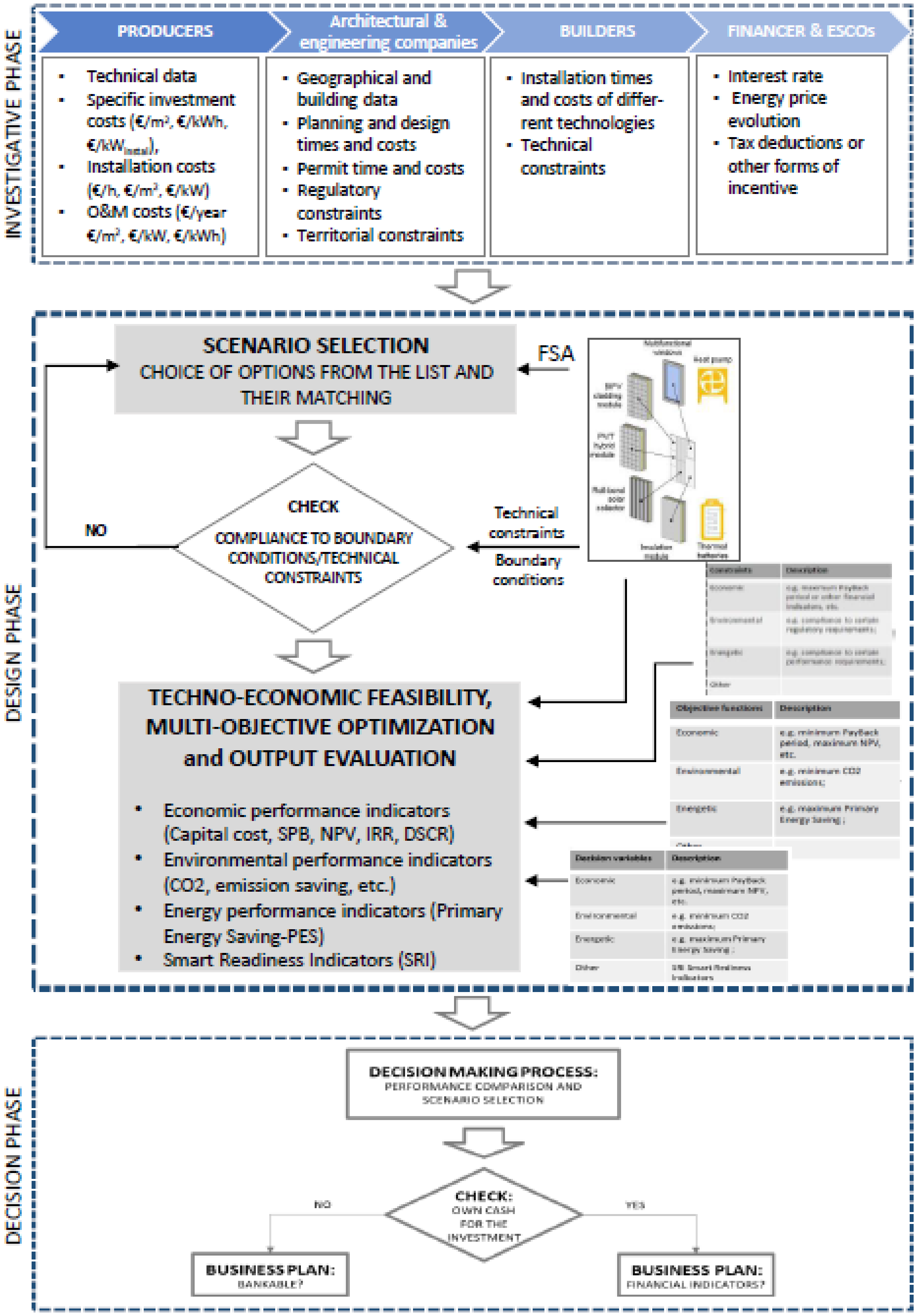

Figure 3. Conceptual scheme of the Early Decision Support Tool

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5.1. The Investigative Phase

The investigative phase concerns data acquisition of buildings, technic/technologies, processes and costs.

The first phase (the input data collection phase) is critical. The application of the decision support system requires knowledge of information relating to the characteristics of the building envelope and the techniques and technologies to be adopted / installed. The detail level of the available information contributes to determining the accuracy of the assessment made through the proposed decision model. The WP1 questionnaire and the existing literature[3] had identified several barriers to technology adoption in home energy retrofit (HER). These include the following: lack of access to information about new technologies; inadequate training about new products; lack of information on installation techniques, inadequate flow of information between manufacturers and industry; mistrust of energy experts and contractors by homeowners; self-interest advertising of EE products by manufacturers giving biased and incorrect information about their products, leading to consumer scepticism; and lack of flow of research from labs to the field.

In order to overcome these barriers, a collection of data is adopted which is completed online. The input data requested consists of information provided by the customer concerning different levels of the building (Figure 4) of a general type (location, size), information on the state of the building (relating to the various energy sources, the forms of energy used, consumption profile), technology (type of heating and cooling systems / techniques, use of renewable sources, etc.).

[3] Ho and Hays 2010; Fuller et al. 2010; Golove and Eto 1996; Plympton et al. 2008; Koebel et al. 2003; National Association of Home Builders (NAHB) 1989; Jaffe and Stavins 1994; Listokin et al. 2001; Partnership for Advancing Technology in Housing (PATH) 2012; Romero 2011 [ongoing]

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General performance indicators (I_1)	
Specific electrical requirement	[$kWh_e/m^2/y$]
Specific thermal requirement	[$kWh_t/m^2/y$]
Overall energy requirement	[$kWh/m^2/y$]
Overall renewable energy penetration factor	[%]
Renewable energy penetration factor (electrical)	[%]
Renewable energy penetration factor (thermal)	[%]
Plant performance indicators (I_2)	
Electrical power	[kW_e/m^2]
Overall power capacity	[kW/m^2]
Utilization factor (electrical power)	[%]
Economic performance indicators (I_3)	
Electricity cost	[$€/m^2/y$]
Thermal energy cost	[$€/m^2/y$]
Overall energy cost	[$€/m^2/y$]
Energetic performance indicators (I_4)	
Primary energy for electricity needs	[$kWh/m^2/y$]
Primary energy for thermal needs	[$kWh/m^2/y$]
Primary energy for the overall requirement	[$kWh/m^2/y$]
Non-renewable primary energy for the overall requirement	[$kWh/m^2/y$]
Environmental performance indicators (I_5)	
CO_{2eq} emissions from electricity	[$kgCO_{2eq}/ m^2/y$]
CO_{2eq} emissions from heating	[$kgCO_{2eq}/ m^2/y$]
Overall CO_{2eq} emissions	[$kgCO_{2eq}/ m^2/y$]
Comfort performance indicators (I_6)	
Deviation below heating set point (sub heating)	[°Ch/y]
Deviation above cooling set point (overheating)	[°Ch/y]
Overall deviation above and below set points	[°Ch/y]

Table 8. Possible performance indicators identified

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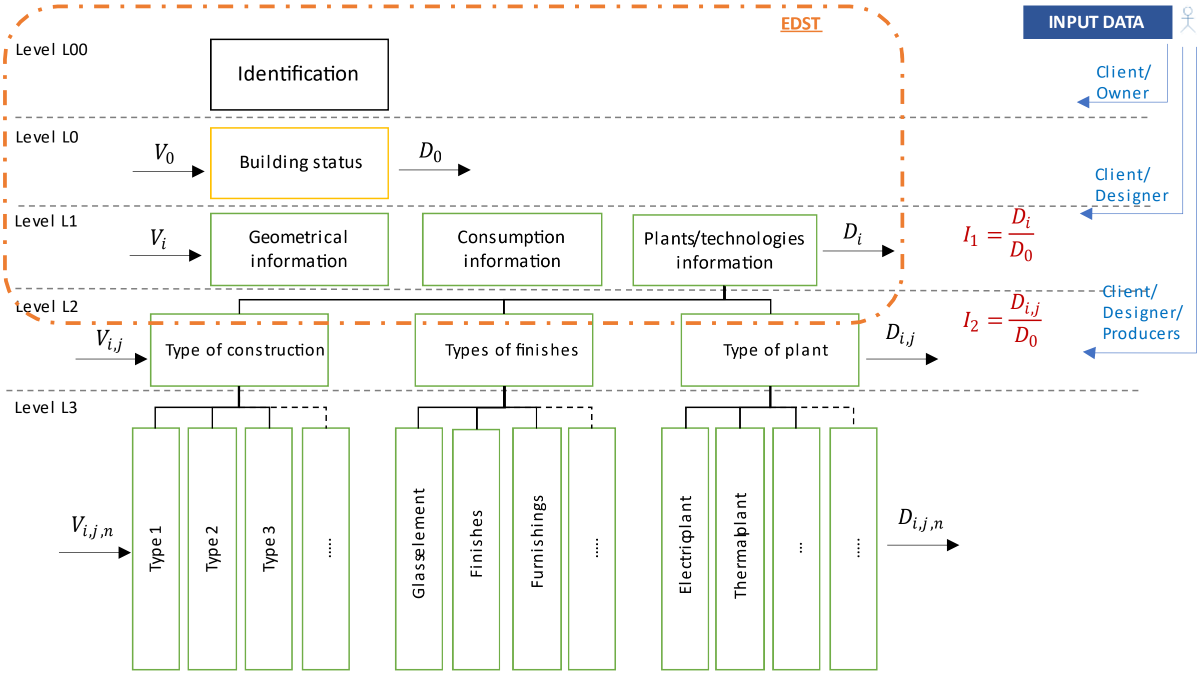

Figure 4. Relationship between the calculated indicators and the information levels

The data provided by customers defines the actual energy indicators shown in Figure 4 and Table 8. In order to evaluate the performance of the building in question, these indicators are compared with reference energy values derived from European or sectoral analyzes. The general performance indices (I_1) evaluate the energy performances in relation to the surface (expressed in square meters). The plant factors (I_2) evaluate the energy impact per net building area. Economic indicators evaluate economic performance by calculating the cost of energy in relation to the net area of the building. It has been decided to allocate the specific cost of electricity per kWh and for thermal energy per m^3 of methane consumed for greater simplicity in the conversion between m^3 and toe. The energy factors evaluate the primary energy supplied to the electrical and thermal needs expressed in toe in relation to the surface. Environmental indicators evaluate the production of CO_2 emissions in relation to the surface. Finally, comfort indicators evaluate the cumulated deviation from the comfort range (set point temperatures).

All these indicators can be expressed in absolute terms, in relation to the floor surface area (net building area) as suggested above, or in relation to the thermal envelope area.

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For the collection of data, the on-line compilation was thought of in two steps:

- STEP 1. Registration to the survey: 1 page of registration will can be included, asking general data from interviewed the user (client/designer/producer).
- STEP 2. The collection data: the survey will be divided into two sections, listed below:

    1. *General data*: representing location, including legal data, contacts, some relevant data for next more technical sections.
    2. *Status*: this section will obtain essential technical data from the building.

The information input will allow different levels of complexity. Inexperienced users could perform a simulation at early stage with very limited data (using default values or assumptions to fill the gaps), and expert users could be able to edit and check more technically advanced inputs.

Below is a suggestion of how these inputs could be organized. The data flow will be organized in Task 3.2, as the data model, data workflow and the software architecture are defined.

Section 1. GENERAL DATA L00, L01

Note: before starting this section, it is suggested to collect all last year energy bills

Identification			
	COUNTRY	**Pull down menu** [list of countries]	Fill in the Country where the building is located
	CITY	**Text**	Fill in the City where the building is located

Building Status			
	PROPERTY	**Pull down menu** **[fully owned/ fully leased/partly leased]**	Owned is a status of full property of goods utilized by client. Leased is a status of contractual obligation on goods of the building with an external owner

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	LOCATION	**Pull down menu** [independent building/ part of building/ etc.]	Specify if the good is addressed on a fully independent building or if it is based on part of a shared building
	YEAR OF CONSTRUCTION	**Numeric Value**	Specify the year of construction of the building
	NUMBER OF FLOORS	**Numeric Value**	Specify the number of floors of the building
	TYPE OF BUILDING	**Pull down menu [residential, non-residential, etc]**	Specify the use of the building
	DWELLING	**Numeric Value**	Specify the number dwelling of the building

Size			
	AREA	**Numeric Value**	**[In m²]** Specify the floor area occupied by the good,
	VOLUME	**Numeric value or nothing**	**[In m³]** Specify the Volume of the good,

The geometric data of the building will be directly provided by the Data Acquisition Tool developed in WP2. If this is available, all areas, volumes, orientations and location are automatically sourced from the building model and the user does not need to enter this information manually.

Section 2. STATUS
L02

Q1. Energy Sources for Building			
	Electrical Energy		**Instructions**
M	**YEARLY CONSUMPTION**	**Numeric Value**	***[In kWh]*** Fill in the value if you know the electric energy consumption of one year. The default unit of measurement is in kWh; specify if you use a different measure unit.
M	**YEARLY COST** **(PLEASE INDICATE THE SUM OF THE AMOUNT DUE OF YOUR ELECTRICITY BILLS)**	**Numeric Value**	**[in Euro]** Fill in the value for the total energy cost of one year of operation. Convert eventually your costs in Euro equivalent. As an alternative, you can provide copies of the energy bills of one year of operation.
M	**REFERENCE YEAR**	**Date**	Specify the year of operation to which the energy consumption and cost are referred.
	Gas / Oil / Fuels		**Instructions**

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	MAIN FUEL TYPE	**Pull down menu [Natural Gas / Coal / Oil / LPG / Other]**	Specify the main fuel type utilized by your dwelling
M	**YEARLY CONSUMPTION**	**Numeric value or nothing**	***[to be specified a unit among: kWh, Nm3, kg, Nliters, other]***. Fill in the value for your total energy consumption of one year of operation. Please, specify the reference unit for the specific fuel.
M	**YEARLY COST** **(PLEASE INDICATE THE SUM OF THE AMOUNT DUE OF YOUR GAS BILLS)**	**Numeric value or nothing**	**[in Euro]** Fill in the value for the total energy cost of one year of operation. Convert eventually your costs in Euro equivalent. As an alternative, you can provide copies of the energy bills of one year of operation.
M	**REFERENCE YEAR**	**Date or nothing**	Specify the year of operation to which the energy consumption and cost are referred.
	Other		**Instructions**
	MAIN SOURCE	**Pull down menu [Biomass / District Heating / Other]**	Specify the type of power supply
M	**YEARLY CONSUMPTION**	**Numeric value or nothing**	***[to be specified a unit among: kWh, Nm3, kg, Nliters; for the index calculation the conversion into kWh is required, e.g., using Net Calorific Value]***. Fill in the value for your total energy consumption of one year of operation. Please, specify the reference unit for the specific fuel.
M	**YEARLY COST** **(PLEASE INDICATE THE SUM OF THE AMOUNT DUE OF YOUR GAS BILLS)**	**Numeric value or nothing**	**[in Euro]** Fill in the value for the total energy cost of one year of operation. Convert eventually your costs in Euro equivalent. As an alternative, you can provide copies of the energy bills of one year of operation.
M	**REFERENCE YEAR**	**Date or nothing**	Specify the year of operation to which the energy consumption and cost are referred.

Q2. Energy Consumption		
HEATING		**Instructions**
MAIN SOURCE FOR SPACE HEATING	**Pull down menu [Electrical/ Fossil fuels / Solar / Biomass / Geothermal / Other]**	Specify which is the main source for space heating in the building
MAIN CONVERSION TECHNOLOGY	**Pull down menu [electrical heaters/ heat pumps/ fuel boiler/ solar thermal/ biomass boiler/ other]**	Specify which is the main source of conversion Technology for space Heating

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MAIN DISTRIBUTION TECHNOLOGY	**Pull down menu [metal radiators / radiant panel (e.g. floor heating) / air ventilation / fan coils / other]**	Specify which is the main plant type installed
MAIN SOURCE FOR PROCESS HEAT	**Pull down menu [Electrical/ Fossil fuels / Solar / Biomass / Geothermal / Other]**	Specify which is the main source for process heat
MAIN CONVERSION TECHNOLOGY	**Pull down menu [electrical heaters/ heat pumps/ fuel boiler/ solar thermal/ biomass boiler/ other]**	Specify which is the main source of conversion Technology for process heat
MAIN SOURCE FOR SPACE COOLING	**Pull down menu [Electrical/ Fossil fuels / Solar / Biomass / Geothermal / Other]**	Specify which is the main source for enterprise cooling
MAIN CONVERSION TECHNOLOGY	**Pull down menu [heat pumps/ inverter chiller/ solar chiller / other]**	Specify which is the main source of conversion Technology for process heat
MAIN DISTRIBUTION TECHNOLOGY	**Pull down menu [radiant panel (e.g. roof cooling) / air ventilation / fan coils / other]**	Specify main plant type installed
ELECTRICAL POWER		**Instructions**
MAIN SOURCE FOR ELECTRICAL POWER	**Pull down menu [grid/ fossil fuels / biomass / solar / wind/ hydro / other]**	Specify which is the main source for electrical power used within the enterprise
AVAILABLE PEAK POWER	**Numeric Value**	**[Kw]** Indicate kW available at peak load
IF LOCAL CONVERSION, SPECIFY MAIN TECHNOLOGY	**Pull down menu [IC engine/ ORC/ PV / WIND MILL / MINI HYDRO / Other]**	Specify which is the main conversion technology for electrical power used within the enterprise

Q3 ENERGY SOURCE -ESCO / Self Produced / …		
IS THERE AN ON-SITE OR OFF-SITE RENEWABLE ENERGY SYSTEM INSTALLED?	**Y/N**	Specify if is installed an energy system based on renewable sources (e.g. solar, biomass, wind, geothermal, hydro)
If yes:		
WHICH KIND OF RENEWABLE ENERGY SYSTEM IS INSTALLED?	**Multiple selection [pv / solar thermal/ geothermal heat pumps/ biomass burner/ wind mill/ mini hydro/ other]**	Select the proper system
PERCENTAGE OF ELECTRICAL ENERGY FROM RENEWABLE SOURCES?	**Pull down menu [different % ranges: 0-5%/ 5-10%/ 10-30%/ 30-50% / over 50%)]**	Select the proper range

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PERCENTAGE OF THERMAL ENERGY FROM RENEWABLE SOURCES?	**Pull down menu [different % ranges: 0-5%/ 5-10%/ 10-30%/ 30-50% / over 50%)]**	Select the proper range
PERCENTAGE OF RENEWABLE ELECTRIC ENERGY SELF-CONSUMPTION	**Numeric Value**	**[%]** Indicate percentage value (range 0 - 100%) related ratio of self consumed renewable electrical energy respect total produced for the same origin
RENEWABLE ENERGY SYSTEMS ADDED VALUE	**Numeric Value or nothing**	**[In Euro/year]** Specify the approximative added value in euros obtained from renewable energy systems installed by your company, as a sum of both energy discounts and feed - in - tariff
REFERENCE YEAR	**Date or nothing**	Specify the year of operation to which the renewable energy data are referred.

Specific measures already adopted

History		
OPENING	**Date**	Specify opening date of the company
LAST SOFT REFURBISHMENT	**Date or nothing**	soft refurbishment of building, i.e. finishes and furnishings only
LAST FULL REFURBISHMENT	**Date or nothing**	full refurbishment of building, i.e. replacement of M&E systems, of finishes, furnishings, equipment and possibly changes of layout
Specific measures adopted – building structure		
Windows	**Y/N**	Specify Y/N whenever the company has adopted specific measures at the building structure on the indicated topics
Envelopes	**Y/N**	
Roof	**Y/N**	
HVAC system	**Y/N**	
Other	**Y/N**	

5.2. The Design Phase

The design phase consists of the analysis performed through simulations. It is the core of the EDST; it provides a procedure suitable for being implemented electronically. (Figure 5)

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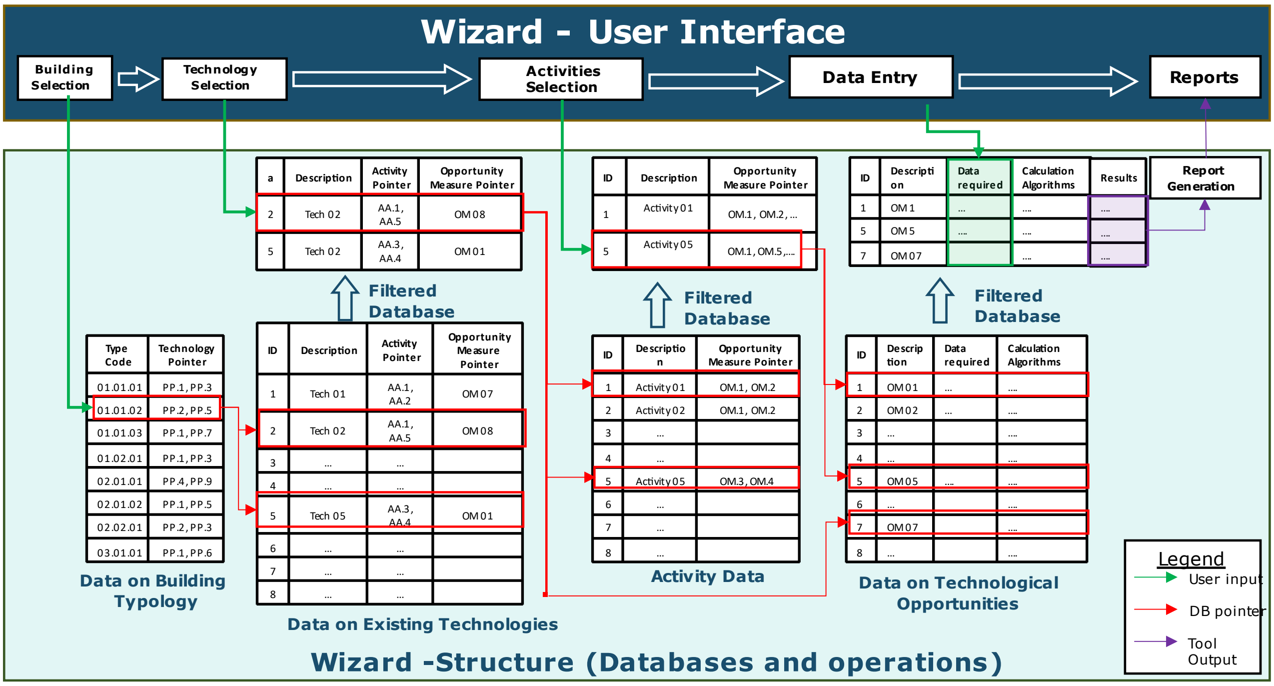

Figure 5. Wizard - User Interface

The procedure requires organising the information in various data store solutions. These will be further defined in Task 3.2 but a possible description is provided below:

1. Creation of **data storage solutions:**

a. *Data on building typology (*single dwelling, residential,...). A generic building is identified by a code. Each building type has indicator reference values taken from European or sector analyses.

b. *Data on existing technologies*. A list of existing technologies for energy production and for the building envelope is created with performance indicators.

c. *Data on Technological Opportunities*. In this list, manufacturers enter their products. In particular, the list will initially be populated with a description and technical-economic performance data of the solutions developed within the ENSNARE project:

- *Active window***.** The active window developed in the project will be a fully industrialised product, manufactured as a modular unit that does not

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require work on site. The technology will allow decentralized ventilation and the incorporation of a heat exchanger integrated within the window frame provides a solution that reduces the energy demand of the building. The active window will be fully integrated with the digital platform enabling an optimum ventilation and heat recovery response.

- *Solar thermal collectors (active building envelope component).* The solution is conceived from a unitized concept, resulting in a panel that contains the main elements at the end of the production line. This design increases the contact surface between the exterior surface that absorbs the solar radiation and the hydraulic circuit that transports the harvested heat. the proposed technology integrates the pipes within the external layer, reducing manufacturing costs, by avoiding manufacturing steps required for integrating pipework inside the sandwich or the cladding. As an alternative, modular hydraulic elements will be explored to convert different claddings into solar thermal collectors. Besides roll-bonding technology and modular hydraulic elements, other advanced technologies to be integrated include ultrasonic welding and the use of optical and corrosion-resistance coatings for improved efficiency and durability.

- *Photovoltaic panels (active building envelope component).* The project will develop of a new set of BIPV façade elements. The use of different high efficiency c-Si cell technologies (back-contact, shingling, coloured cells, etc.) is envisaged in order to match both energy and aesthetical requirements. In addition, some of the possible substrates lead to lightweight solutions, thus offering additional advantages.

- *Hybrid photovoltaic/thermal (PVT) panel (active building envelope component).* Hybrid solar photovoltaic-thermal technology could represent a more efficient solution even if this technology still presents some drawbacks (namely the long-term durability of the collectors shorten lifespan and reduce competitiveness and their installation increases system investment and reduces collection potential). Within the project, a new solution for the exploitation of the hybrid energy of the building envelope will be developed, valid for mounting on the facade and on the roof, to

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simultaneously convert the solar resource into heat and electricity. The main innovations beyond the state of the art will improve the durability of the PVT collector by: 1) addressing different solutions (lamination, mechanical, adhesive, etc.) for long-term large format PV-absorber stability, reducing PV cell cracks while ensuring good thermal contact; and 2) mitigating internal corrosion (inner face of the pipes or roll bond absorber) by means of protective coatings. Furthermore, the hybrid PVT collector will integrate specific features to enable its use as a building envelope element, focusing not only on the handling system but also on its plug & play installation.

- *Innovative heat pump.* The project plans to combine enclosures and energy production systems with advanced heat pumps for energy production combined with storage devices.

- *Energy storage and conversion components*. Compact thermal batteries, both electric and salt-based, will be used to store the solar thermal energy collected by the active components of the building envelope. The main innovation will be based on the full integration of the system with the envelope mesh, the building components and a heat pump capable of converting electrical energy into thermal energy. The project intends to exploit the interaction capabilities of these technologies by integrating them into a holistic system that collects, stores and supplies electrical and thermal energy. Components can be connected to the Digital Twin and operated directly from the Smart BMS. In addition, the system will be integrated within the digital platform ENSNARE thus allowing the management of energy loads, ensuring the reduction of load peaks and exploiting the accumulation of excess power.

d. *Activity data*. In this list producers and designers could enter the activities which are needed to implement the efficiency improvement opportunities with description, time, costs of the activity and constraints to the activity. Then, each opportunity will be characterized by a set of activities describing its life cycle.

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2. **Data Entry.** As already seen in the previous section, the customer enters data in on-line mode.

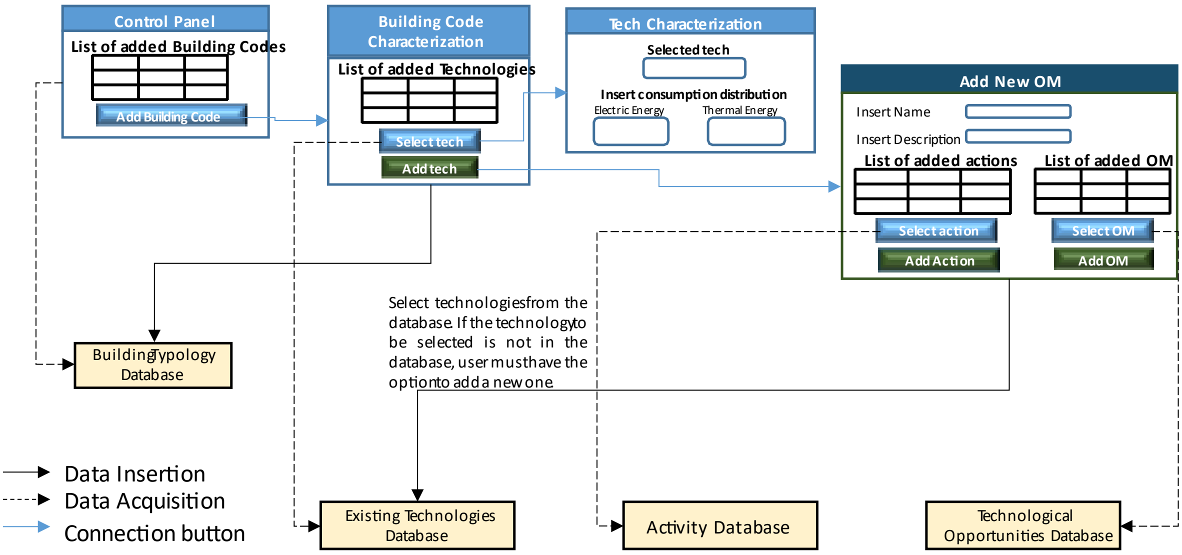

Figure 6. Example of EE User Interface

Algorithm. The algorithm, that will be developed from T3.2 and T3.3, a multi-objective model (MODM) provide support for the decision maker in identifying a range of alternatives. This phase integrates models identified in task 3.2 and task 3.3. Besides technical constraints for each considered technology, site-specific boundary conditions are also considered. Finally, concerning the constraints imposed on the output of the multi-objective optimization model, mainly the compliance with some threshold value of economic indicators such as e.g. maximum payback time and minimum debt service coverage ratio (DSCR) could be imposed as a constraint of the developed model. The critical parameters influencing the decision-making phase will be considered as decision variables of the multi-objective optimization problem. Between the decision variables considered within the DSS for the development of the online toolbox will be also the specific value of the economic grants linked to the environmental and energetic benefits (such as the Italian TEE, corresponding to one TOE of primary energy saving).

Since the main goal of this tool is the identification of viable solutions for the retrofitting of buildings from a sustainability perspective, the objective functions

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of the multi-objective optimization problem will be selected according to the stakeholders' different conflicting objectives, as presented in Table 9. Each stakeholder is indeed the bearer of different instances, such as profit maximization accounted for by conventional economic indicators (e.g. IRR), minimization of bill cost, minimization of greenhouse gas (GHG) emissions to name a few, thus adopting an overall sustainability perspective. For the assessment of the advantage of a building retrofitting from the point of view of primary energy consumption reduction, the Primary Energy Saving ratio (PESR) can also be used in the optimization algorithm, calculated as the energy recovered over the entire heating/cooling season. PESR) as defined by G. Chicco, P. Mancarella, 2009[4], i.e. the ratio of the saving energy guaranteed by the adoption of the new solution in comparison to the energy consumption of the conventional (old) solution.

$$PESR = \frac{E_{old} - E_{new}}{E_{old}}$$

The main environmental criterion suggested in this document is the carbon dioxide emission reduction (CDE). The avoided GHG emissions and PESR due to the building refurbishment are calculated through the appropriate emission and conversion factors of the reference fuel, as in (P. Simenoni, G. Nardin, G. Ciotti, 2018)[5] and reported in Table 10.

Stakeholder	Objective function	Optimization
Service provider	IRR	Maximization
	PB	Minimization
Investors	DSCR	Maximization
Users/Engineers	Heating expenditure	Minimization
Users/ Engineers /Architects	PES	Maximization
	GHG emissions	Minimization

Table 9. Example goals of multi-objective optimization

[4] G. Chicco, P. Mancarella, Distributed multi-generation: energy models and analyses, Nova Science Publishers, Hauppauge, New York (2009)

[5] P. Simeoni, G. Nardin, G. Ciotti, Planning and design of sustainable smart multi energy systems. The case of a food industrial district in Italy, Energy, 163 (2018), pp. 443-456

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Primary energy		Carbon dioxide emissions	
ξ_{GRID} (TOE/kWh_{el})	ξ_F (TOE/Sm^3_{CH4})	μ_{GRID} ($MgCO_2$-eq/kWh_{el})	μ_F ($MgCO_2$-eq/Sm^3_{CH4})
1.87E-04	8.20E-04	4.22E-04	1.94E-03

Table 10. Example goals of multi-objective optimization

5.3. The Decision Phase

Having identified the feasible solutions from a technical-economic and environmental perspective, the last step of the methodology involves the development of a decision-making model to assist with the final choice among the identified solution sets depending on funds availability. As a result, the output of the process will be an overall summary report. As mentioned above, the EDST aims to be a useful working tool for professionals who are involved in the process of refurbishing the building. For this reason, given the above-mentioned users and their needs, the results report can be divided into two sections. The first section presents a summary of the data entered by them, organized by highlighting the main characteristics of the building that are relevant to energy efficiency.

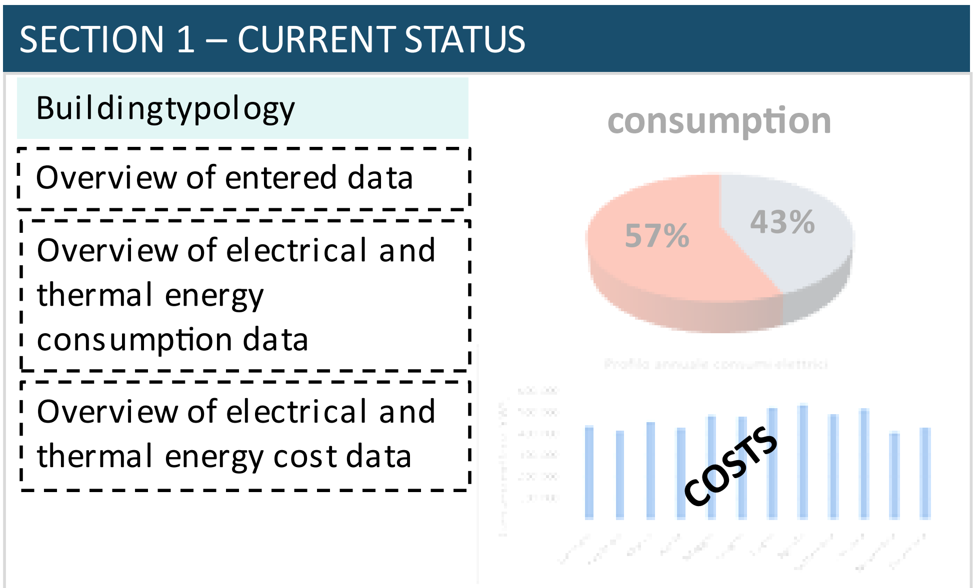

Figure 7. Section 1 - Current Status

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The performance indicators, Table 2, obtained by processing the information for the techniques/technologies identified and calculated in economic, energy and environmental terms will be reported in Section 2.

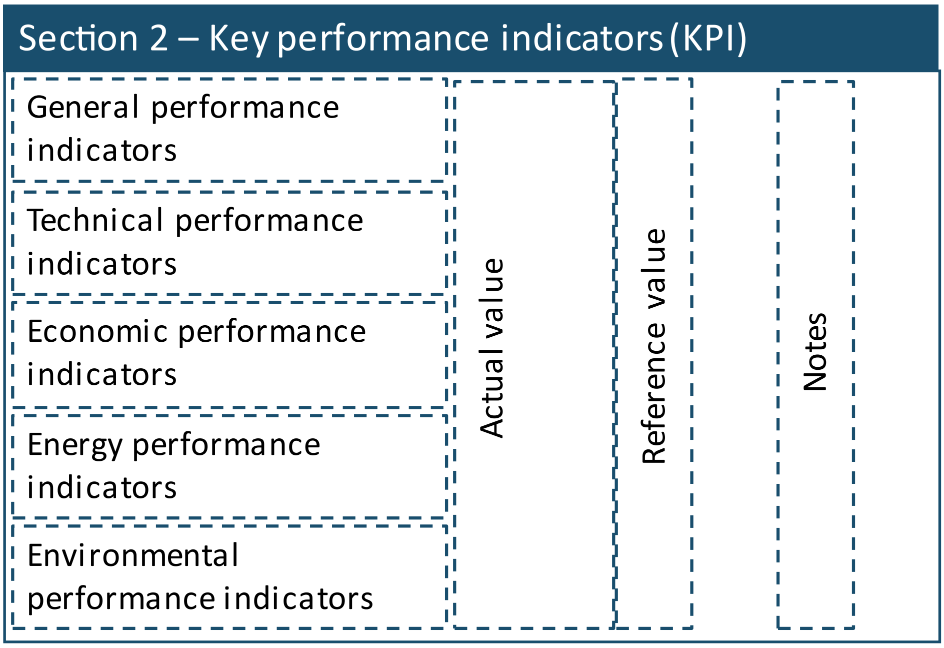

Figure 8. Section 2 - Key performance indicators (KPIs)

Section 3 outlines the Opportunity Measures (OM) identified describing them technically and quantifying in economic, energy and environmental terms the potential savings that can be achieved through their adoption.

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SECTION 3 – OPPORTUNITY MEASURES

	OUTPUT financial				OUTPUT Energetic-environmental			
TECHNOLOGY	**PB [y]**	**NPV [EUR]**	**DSCR**	**IRR [%]**	**PES [tep]**	**CO2 [t]**	**Renevable [%]**	**SRI [%]**
Solution 1 description Solution 2 description								
Solution 3 description								
Solution 4 description								

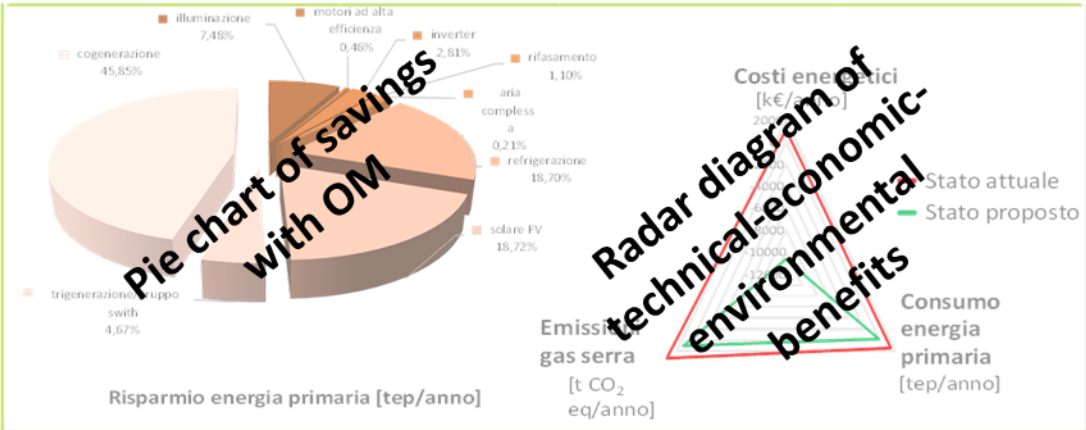

Figure 9. Section 3 - Opportunity measures

The output from the Decision Phase is forwarded to a visual 3D representation on a web-based visualization platform. The core of the platform will be a web application to visualize BIM files (in IFC format) and the ventilated façade panels, those that have been selected by the EDST as the most suitable, in browsers without any extra plugins or programs. The idea is to implement a one-page web application with a modular architecture, where it is intended to create reusable applications, libraries, and modules. These front-end components must be developed using the W3C standards, to ensure the compatibility of the application across all operating systems and most web browsers. The only restriction for the execution of the application should be limited to the capabilities of the computer and the web browser to display 3D content. Specifically, it will be capable of running on all operating systems that have a WebGL-compatible browser.

The front-end and backend will communicate through restful web services. The communication should be secured to guarantee the integrity of all transmitted data, using secure connections (https) and applying some encryption methods.

Using these communications, an API will be implemented to receive the BIM model generated in the WP2. This model will be the central element in the visualization platform where the user can view and/or edit the physical appearance and layout of the selected renovation solution.

On the 3D of the building, which has been loaded in a 3D web environment, the panels of the ventilated façades will be placed. For this, the parameters that have been the result of the EDST algorithm will be obtained using an API to connect the EDST with the web BIM visualization platform. Based on the parameters obtained and the resultant panels characteristics, a grid (the envelope mesh) will be generated to show the user the physical placement of the panels on the façade.

This grid will be easily configurable to perfectly match the panels over the shape of the different façades considering windows, doors and other elements.

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6. Product requirements

This section summarises the product requirements and functionalities that have been identified in this Task.

Product perspective	The ENSNARE EDST aids the design of a renovation proposal in a first iteration, maximising reduction of time and costs and optimising information provided to the client.
Product functions and features	F1 Information input F2 Generation of renovation scenarios F3 Energy simulation F4 Life cycle environmental assessment F5 Life cycle cost assessment F6 Multi-criteria assessment of scenarios F7 Information output
User classes and characteristics	Expert (e.g. designer) Non-expert (e.g. client)
Operating environment	Online tool, no installation needed

Table 11. Description of overall requirements for EDST

F1 Information input	
F1.1 Geometry information	Options: • From Data Acquisition Tool • From predefined archetypes
F1.2 Basic information	Building type and age Energy source and HVAC system type, energy bills Use and occupancy (predefined patterns)
F1.3 Advanced information	Construction characteristics Detailed information of energy systems

	Use and occupancy (set points, timeframes)
F1.4 Database of solutions	Information is provided by system and product manufacturers to the ENSNARE team, which validate and include it in the database
F2 Generation of renovation scenarios	
F2.1 Scenario generation	Renovation packages that can be suited to the building and its existing conditions/systems
F2.2 Scenario filtering	Based on constraints (e.g. rule-based) or on previous findings and assumptions (e.g. using AI)
F3 Energy simulation	
F3.1 Energy simulation	Dynamic simulation with e.g. hourly outputs of internal temperature and energy use
F4 Life cycle environmental assessment	
F4.1 LCA	LCA considering whole life cycle (manufacturing, operation…) to obtain associated GHG emissions for each renovation scenario
F5 Life cycle cost assessment	
F5.1 LCCA	Financial assessment considering costs at all stages: investment, operation… obtaining relevant economic indicators for each renovation scenario
F6 Multi-criteria assessment of scenarios	
F6.1 Weighting factors	Options: • Predefined weighting factors to comfort, energy, environment, cost, etc. based on user type • Possibility of editing weighting factors
F6.2 Multi-criteria ranking	Application of weighting factors to obtain ranking of solutions as per their suitability to the building/client

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F7 Information output	
F7.1 Basic information	Ranking and description of solutions
F7.2 Graphic information	Plots and visual comparison of solutions
F7.3 Advanced information	Possibility for checking detailed outputs for expert users

Table 12. Description of system features for EDST

Performance requirements	The tool should work in any regular laptop or mobile phone, avoiding problems related to computational capacity.
Safety requirements	The information provided by the DSS must meet safety regulations.
Security requirements	The tool should guarantee privacy of the information and fulfilment of local laws regarding data protection.
Software quality attributes	The EDST should be easy to understand and use with limited training effort.
	The graphical user interfaces (GUI) of the tool should be friendly and easy to use.
	Language in any screen, form or message window, should be English.
	The tool should be available any time and every day (24/7).
	The tool should be developed in a way that allows the possibility to test each module separately with minimum effort.
	The tool should be developed in a way that modules can be located in the same or different servers.

Table 13. Description of other non-functional requirements for EDST

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7. Conclusions

As 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 through the development of an industrialized envelope mesh and of a digital platform that will interconnect all ENSNARE's solutions.

This report represents the first step of the development of the early decision support tool (EDST). The tool is an integral part and a key component of the digital platform, providing different types of users with information and context for a wide range of energy renovation technologies.

Based on the outputs provided by WP1, a number of different roles involved in the renovation process, use cases and their target stakeholders have been identified and classified in Chapter 4.

Chapter 5 describes the structure of the Early Decision Support Tool. As aforementioned, the EDST will perform a pre-feasibility analysis of different retrofit options, providing the various actors involved in a retrofit project with an overview of the economic and environmental impact of their choices and to allow a more conscious decision-making process.
The conceptual scheme of the Early Decision Support Tool has been subdivided in three typical phases:

- The *Investigative Phase* concerns data acquisition (characterization of the buildings, technologies and users).
- The *Design Phase* consists of the analysis performed through simulations.
- The *Decision Phase,* the last step of the methodology, involves the development of a decision-making model to assist with the final choice among the identified solution sets. The summary report will be subdivided into sections:
    1. Section 1 will present a summary of the data entered.
    2. Section 2 will indicate the Key Performance Indicators obtained.
    3. Section 3 will outline the Opportunity Measures (OM) identified.

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The output from the Decision Phase is forwarded to a visual 3D representation on a web-based visualization platform.

Finally, Chapter 6 summarises the product requirements and functionalities that have been identified. In particular, Table 11 describes the overall requirements for EDST, Table 12 summarises the system features for the EDST and Table 13 summarises the other non-functional requirements for the EDST.

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