RINNO PROJECT

Report

An augmented intelligence-enabled stimulating framework for deep energy renovation delivering occupant-centred innovations

Deliverable 6.1: RINNO Components Integration, Suite and Acceptance Tests

Work Package 6: Integration, Demonstration, Evaluation & Replication Potential

CERTH

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Executive Summary

Deliverable D6.1 "RINNO Components Integration, Suite and Acceptance Tests" documents the work performed in Task 6.1, focusing on the integration of the diverse digital tools developed in RINNO into a unified platform — the RINNO Suite. The suite provides a holistic digital environment to support all phases of the building renovation lifecycle: planning and design, construction and retrofitting, and the use phase after renovation.

The RINNO Suite brings together tools initially developed as stand-alone components under WP3, WP4, and WP5. Their integration required significant effort to ensure smooth information flow, interoperability, and role-based access through a central User Management System. Each stakeholder (e.g., building owners, construction managers, technology providers, occupants) can access the appropriate tools using secure credentials and a unique Pilot ID that ensures correct association of data with a specific renovation project.

The platform enables:

- User-friendly workflows across all renovation stages.
- Seamless exchange of static and dynamic data (BIM, sensor data, monitoring outputs).
- Centralised authorization and role-based access.
- Collaboration through shared Pilot IDs and a social communication layer.
- Workflow continuity supported by digital contracts and notifications.
- Integration of procurement and monitoring functions through a dedicated Marketplace.

The integration followed a staged approach:

1. Establishing connections between tools within each renovation phase.
2. Linking the phases together (design → construction → use).
3. Hosting tools within the RINNO Suite via iFrame technology for modular embedding.
4. Aligning all tools with the central User Management System to enforce security and interoperability.

Testing and validation were conducted extensively, with multiple tool versions iteratively refined. The KRIPIS Smart House pre-pilot provided a controlled environment to practice workflows, test monitoring sensors, and perform 3D scanning prior to deployment in the larger demo buildings. The integrated suite includes:

- Planning and Design Assistant (WP3): Tools for simulation, LCA/LCC analysis, renovation scenario selection, and job scheduling.
- Retrofitting Manager (WP4): Modules for prefabrication, planning, AR-based training, logistics, and site management.
- Building Lifecycle Renovation Manager (WP5): Tools for the use phase, including the Renovation Roadmap, Building Logbook, Building Monitoring (Dashboard + Monitoring system), Sensor-Enabled BIM model, Marketplace, Social LCA tool, and Online Digital Contracts.

Acceptance tests confirmed that:

- Renovation roadmaps correctly update energy, cost, and CO_2 indicators.
- Monitoring dashboards and time-series tools display accurate sensor data in near real-time.
- The Sensor-Enabled BIM model correctly overlays dynamic data and triggers notifications for anomalies.
- The Marketplace supports end-to-end workflows for technology providers and construction managers, with PayPal developer integration.
- Online contracts are automatically generated at workflow milestones and block progression until signed by all stakeholders.
- The integration of retrofitting tools ensures synchronisation of prefabrication, planning, and logistics with job scheduling.

The integration of RINNO tools into a single suite represents a first operational result in enabling digital collaboration for deep renovation. It demonstrates the feasibility of connecting diverse tools and stakeholders within one platform, while also revealing areas for further optimisation in workflows, interoperability, and user experience. More importantly, it highlights how owners, managers, designers, and technology providers can work under a unified digital environment, paving the way for more efficient, transparent, and occupant-centred renovation processes.

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Acronym	Full Form
API	Application Programming Interface
AR	Augmented Reality
BIM	Building Information Modelling
BLRM	Building Lifecycle Renovation Manager
CAPEX	Capital Expenditure
CERTH	Centre for Research and Technology Hellas
CIRCE	Centro de Investigación de Recursos y Consumos Energéticos
CL	Contract Lifecycle
DCU	Dublin City University
DSS	Decision Support System
EE	Energy Efficiency
EU	European Union
GA	Grant Agreement
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
HVAC	Heating, Ventilation and Air Conditioning
ID	Identifier
INTEMA	Integrated Energy Management
JSO	Job Scheduling Optimiser
JSON	JavaScript Object Notation

JWT	JSON Web Token
KPI	Key Performance Indicator
KRIPIS	Smart House research facility (Greece)
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
MQTT	Message Queuing Telemetry Transport
NDA	Non-Disclosure Agreement
OPEX	Operational Expenditure
RINA	Registro Italiano Navale
RINNO	Deep Renovation Project funded under H2020
RPDA	RINNO Planning and Design Assistant
RRM	RINNO Retrofitting Manager
SC3	Secure Cloud Cluster 3
SFTP	Secure File Transfer Protocol
s-LCA	Social Life Cycle Assessment
UTAUT	Unified Theory of Acceptance and Use of Technology
VR	Virtual Reality
WP2, WP3, WP4, WP5	Work Package 2, 3, 4, 5

1 Introduction

The present report is a confidential deliverable (D6.1 “RINNO Components Integration, Suite and Acceptance Tests”) of the RINNO H2020 funded European project (GA 892071).

1.1 Scope and Objectives of Deliverable D6.1

The main aim of this Deliverable is to present the work conducted in the framework of Task 6.1 – ‘Integration of RINNO Components and Acceptance Tests’ regarding the integration of the individual components of the RINNO Suite to a unified Platform facilitating all stages of the renovation.

The RINNO Suite comprises all the IT tools developed under the WP3, WP4 and WP5 which aimed at the design, construction and use phase of the building respectively. These were developed at a first stage as stand-alone software within the various WP, while within the activities of Task 6.1 they were integrated into a complete Suite of tools ensuring the seamless communication and flow of information between them in order to provide an efficient and interoperable platform that enables user-friendly experience on the renovation and facilitating the uptake of renovation projects. The RINNO Suite of tools addresses all stages of the renovation, namely design, construction and post-renovation (use phase) taking into account i) the timing of the activities, thereby ensuring sequential use of the various components depending on the stage of the renovation relevant to each component, and ii) the different actors/stakeholders of the renovation; these have different access to the various tools of the platform depending on their role in the project and the specific building that they are working on. In addition, the middleware equipment was also integrated to the RINNO Suite, linking and presenting monitoring data from the sensors from each demo building to that specific building.

Having defined the connections between the components and the functionalities of the RINNO Suite, a set of tests were conducted to ensure that the integration was successful and the objectives for the platform were achieved. Integration tests were conducted i) between the tools within the three main components of the RINNO Suite representing the different stages of the renovation (RINNO Planning and Design Assistant for the design stage, RINNO Renovation Manager for the installation/construction stage and RINNO Building Lifecycle Renovation Manager for the use phase) to ensure that the process at each stage is conducted successfully, and ii) between the main components in order to test the communication and confirm the successful information exchange between the different renovation stages (for example to ensure that the user of the tools at the construction stage receives all necessary information from the design tools when logging to the platform). Once the platform was developed and tested and all bugs were addressed, the platform was presented to the demo leaders and relevant external stakeholders. These were given access to the platform and provided feedback on to evaluate the acceptance of the RINNO Suite and its suitability as a renovation tool for the whole value chain of the renovation.

1.2 Relation with other Tasks and Deliverables

Task 6.1 deals with the integration of the components developed in WP2, WP3, WP4 and WP5 in order to develop the RINNO platform. This is then used for the training of the demo leaders and relevant stakeholders involved in the renovation in the four demo buildings (T6.2) and for the demonstration during the renovation (T6.3). This is shown schematically in Figure 1-1 below. Outputs from WP2–WP5 feed into Task 6.1, where the individual tools are integrated and tested as a unified platform. Task 6.2 also validates the RINNO Suite in demo sites.

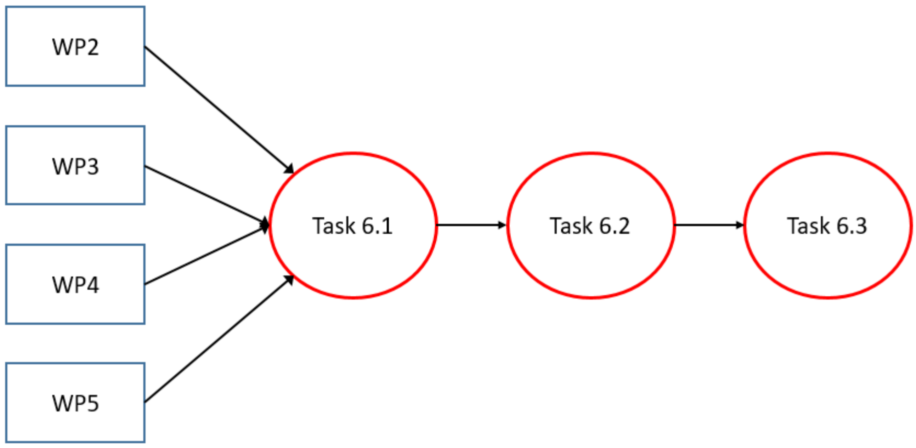

Figure 1-1: Schematic representation of the relations of Task 6.1 with other tasks and WPs

1.3 Structure of the Deliverable

The structure of the Deliverable is as follows:

In **Section 2,** an overview of the RINNO Suite is presented where the features of the main components of the platform are presented, namely the RPDA, the RRM, the BLRM and the Middleware as well as the general workflow of the Suite are demonstrated.

In **Section 3**, the Integration Methodology of these individual tools and components into a unified platform is presented

In **Section 4,** the lessons learnt from the work conducted are discussed
In **Section 5,** the conclusions of this report are presented

2 The RINNO Suite

The RINNO Suite was developed to support all stages of a renovation project, namely the design stage, the construction/renovation stage and the use phase of the building post-renovation. For this reason, the RINNO IT tools were grouped accordingly into three main components of the Platform addressing the needs of each stage. These main components and the renovation workflow of the Platform are presented in the following paragraphs.

2.1 RINNO Suite Components

The RINNO Suite comprises three main components, each developed to address a specific stage of the renovation.

2.1.1 The RINNO Planning and Design Assistant (RPDA)

The RPDA is the part of the RINNO Suite which encompasses the software tools supporting the design stage of a renovation project. This includes the tools for the holistic analysis of alternative renovation scenarios considering multiple performance aspects (energy, environmental, disruption) and the selection of the best scenario according to the user's preferences as well as the optimum renovation schedule (at the design stage). In general, the RPDA component of the RINNO Suite comprises the tools developed during the activities of WP3, namely:

- The Digital Twin tool for conducting preliminary fast estimations of the baseline and drafting potential renovation scenarios
- The INTEMA.building tool for the detailed energy assessment of the renovation scenarios
- The VERIFY tool for conducting LCA/LCC analysis of the potential scenarios
- The TEA tool for evaluating disruption impacts and waste generation during renovation.
- The Renovation Scenario DSS for selecting the best renovation scenario that meets the user's requirements
- The Job Scheduling Optimizer for generating the optimum schedule of works for the renovation, both short-term and long-term, considering general works at the design stage.
- The social-LCA tool which assesses the social impact of the renovation (at the baseline and estimation at the design stage)

2.1.2 The RINNO Retrofitting Manager (RRM)

The RRM encompasses a set of tools which support the construction stage of a renovation project aiming at reducing the onsite time and cost of the installation/construction processes. These include

- A recommendation tool which, according to the user preferences, suggests the amount of work that can be completed offsite and onsite;
- A process optimization tool which takes into account specific site constraints and refines the retrofitting schedule accordingly

- A retrofitting scheduling component which enables the user to review, validate and, if necessary, amend the renovation schedule.
- An Onsite Monitoring component (E-cockpit) which provides real-time multi-disciplinary KPIs and updated reports on the progress of the renovation
- An AR/VR tool is also provided through the RRM which facilitates quick training of workers in a safe environment
- In addition, the RRM is also accompanied by a logistics platform (E-logistics tool) which monitors and organizes the deliveries onsite to enable better control of the whole value chain.
- Finally, the Job Scheduling Optimizer is also available as a sub-component of the renovation/installation package to enable the users to generate the detailed day-to-day work schedule (based on the feedback from the retrofitting scheduling component of the RRM).

2.1.3 The RINNO Building Lifecycle Renovation Manager

The **RINNO Building Lifecycle Renovation Manager** includes a set of tools for the use phase of the building as well as tools for supporting transactions between stakeholders of the renovation. These include:

- **Renovation Roadmap**, which allows users to define and compare different renovation pathways. Each roadmap starts with the baseline performance of the building and progresses step-by-step through renovation measures, dynamically updating indicators such as primary energy demand, CO_2 emissions, costs, and savings.
- **Building Logbook**, which consolidates key building-related information by combining static with dynamic data from monitoring and renovation activities. It acts as a long-term record of the building's performance and renovation history. It consists of:
    - **Building Monitoring**, which provides access to performance dashboards and time-series monitoring of energy demand, environmental conditions, and system operation. It allows users to compare expected and actual values and validate the effectiveness of renovation measures.
    - **Sensor-Enabled Building Model**, which integrates real-time sensor data with static BIM information, creating a digital twin of the building. This immersive model supports visualization of live conditions and highlights malfunctions or deviations directly in the 3D environment.
    - **Static Building Information**, which stores essential design and construction details about the building, serving as a reference dataset for monitoring, planning, and lifecycle management.
- **Marketplace**, where users can browse and procure innovative renovation solutions, technologies, and materials, with technical specifications, supplier information, and potential AR-based resources to support installation and training.
- **Social LCA Tool**, which gathers feedback from building occupants to assess the social and user-related impact of the renovation, linking lived experience with technical

performance results.

- **Online Contracts**, which manage legally binding agreements digitally. They are automatically triggered at key renovation workflow milestones, ensuring that renovation steps only proceed once the required stakeholders have signed.

A view of the GUI of the implemented platform which encompasses all the aforementioned software tools is presented in Figure 2-1.

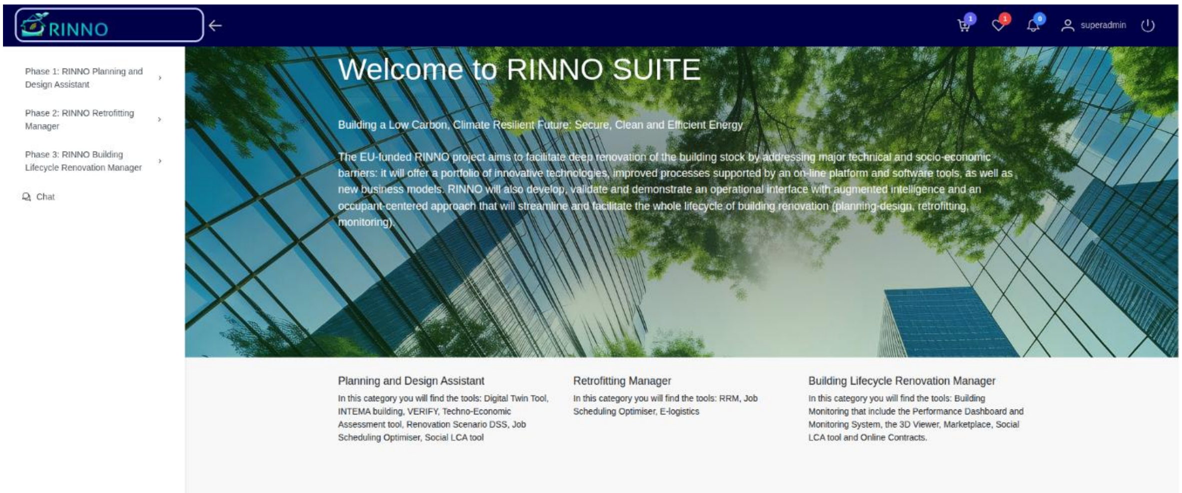

Figure 2-1: overview of the RINNO Suite of IT tools

2.1.4 Middleware

The RINNO approach to renovation facilitates informed decision-making with the use of actual monitoring data from the building. To do so, a range of monitoring sensors were installed at the demo buildings to obtain data from the building operation; a comprehensive description of the monitoring plan for each demo building is provided in Deliverable 'D5.4 – Mutli-purpose IoT Enabled Building Monitoring (Final Version)'. The availability of these data to the RINNO Suite is achieved through the integration of the **Middleware** component, an essential system designed to facilitate the collection and management of data from a diverse array of devices installed across various pilot sites. This robust component is engineered to understand and interact with all types of devices, regardless of their manufacturer or communication protocol.

Key Features of the Middleware are:

- Data Collection and Integration: Middleware acts as a central hub that collects data from numerous devices, ensuring seamless integration and communication between disparate systems. The component is capable of interpreting and processing data from sensors, IoT devices, and other digital instruments deployed at the pilot sites.
- Data Storage and Management: Once collected, the data is securely stored within the system, ensuring its availability for real-time and historical analysis. Advanced storage solutions are implemented to handle large volumes of data, providing scalability and reliability.

- Handling Missing Data: Middleware is equipped with mechanisms to address scenarios where data might be missing or incomplete. These mechanisms include:
    - Data Interpolation: Estimating missing values based on the available data points.
    - Alert Systems: Notifying administrators when data gaps are detected, allowing for timely manual intervention
- Real-Time Data Transmission with MQTT: For real-time data communication, Middleware utilizes the MQTT (Message Queuing Telemetry Transport) protocol. MQTT is highly efficient and suitable for environments where bandwidth is limited, ensuring timely and reliable data transmission from the devices to the Middleware.
- Data Verification with Parsers and REST API: To ensure the integrity and accuracy of the data transmission, various parsers have been implemented within the Middleware. These parsers continuously double-check the transmitted data by comparing it against historical records. The component uses REST API connections to access and retrieve historical data, enabling comprehensive data validation and consistency checks

In summary, the Middleware component is a sophisticated and versatile system crucial for the effective collection, storage, and validation of data from a wide range of devices in pilot sites. Its ability to handle real-time data via MQTT and verify data integrity through parsers and REST APIs ensures high reliability and accuracy in data management.

2.2 General Workflow of the RINNO Suite and Interconnections between components

In general, the RINNO process for building renovation is as follows.

- At first, the designer (or different members of a design team) assesses the performance of potential renovation scenarios against multiple aspects with the use of the RPDA tools and the best renovation alternative is selected according to the user's preferences. At this stage, the optimum general work schedule is generated and is then fed to the RRM
- The work scheduled in the previous stage is then further refined according to specific site restrictions from members of the onsite construction team with the use of the RRM tools. Based on this refined work plan the detailed day-to-day work schedule is then generated for the construction/installation process. Efficient construction process is supported by the logistics management tool as well as the AR/VR training material accessible to the workers onsite and the progress of the renovation is monitored through suitable KPIs.
- After the renovation works finish, the environmental conditions and the energy consumption of the building are monitored to assess the effectiveness of the retrofit and provide recommendations to the occupants for the energy efficient use of the building. Additionally, features such as the Marketplace and Smart contracts facilitate the introduction of innovative technologies/business models and enable automatic

purchases which ultimately accelerate the whole renovation process.

The renovation approach proposed by RINNO is not a static straightforward process where the work in each stage of the renovation is independent/isolated from the rest; it is a dynamic process where information is shared between the various stages for reducing errors, maximizing the efficiency of the construction and minimizing the discrepancy between the design and the as-built performance. As such, there are several interconnections between the various tools which allow the seamless flow of information and were required to be taken into account during the integration of the individual IT tools to the RINNO platform. An overview of these interconnections between the tools and technologies developed in the various WPs is presented in Figure 2-2.

WP2 provides the specifications needed for both simulations and AR scenarios. These specifications are passed on to WP3 and WP4 so that they can use them in their tools and methods. WP2 also connects with the Marketplace to bring in third-party technologies.

WP3 focuses on the design phase. It produces outputs such as theoretical performance assessments, BIM models, and a general work schedule. These results are then shared with WP4 and WP5 to support construction planning and post-renovation activities.

WP4 deals with the construction stage. It uses inputs from WP2 and WP3 to prepare AR/VR scenarios and BIM models that help visualise and plan the works. These outputs are also provided to WP5.

WP5 represents the use phase. It collects monitored data from the demo buildings and integrates results from WP3 and WP4 (BIM models, performance data). This monitored information is then fed back to WP2, creating a loop that helps refine specifications for future projects.

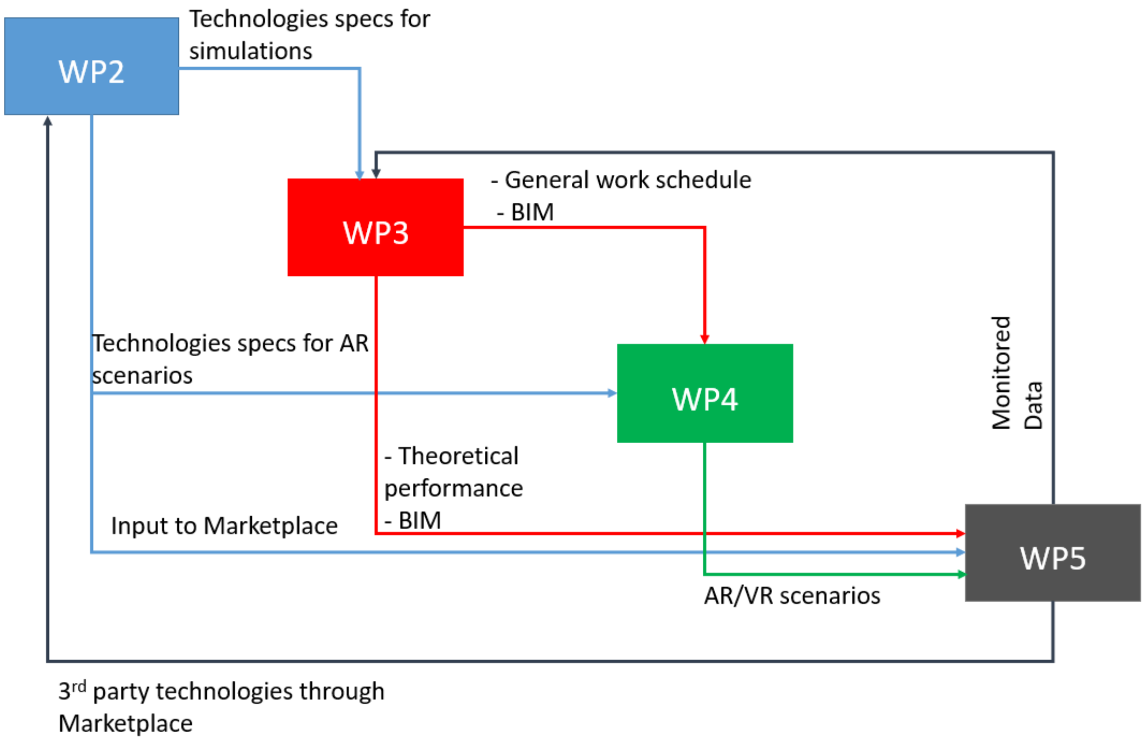

Figure 2-2: Interconnections of IT tools in the RINNO platform

The main interconnections between the different WPs described in the figure above are as follows:

- The IT tools of WP3 received all necessary specifications of the technologies required for the simulations from the technologies developed in WP2. Similarly, WP4 receives relevant input regarding the technologies for the AR training scenarios and WP5 for the Marketplace from WP2
- The output of WP3 involves the selection of the optimum renovation scenario and the optimized general work plan. This work plan, along with the BIM file of the building is fed to the RRM in WP4 for the site construction works to commence
- Furthermore, the expected energy performance of the building for the renovation scenario (WP3) is used as input in the Performance Dashboard (WP5) to compare the design with the as-built performance
- The AR training scenarios developed in WP4 are accessible through the Marketplace (WP5). Their use though is achieved through a downloadable file that is compatible with Android system.
- Monitored data from the demo buildings (WP5) are fed to the VERIFY platform and the social LCA tool (WP3) for the assessment of the renovation
- Finally, it is possible to introduce additional technologies both from the RINNO technology providers and third-parties through the Marketplace

3 Integration Methodology

The integration methodology employed is a sophisticated and well-structured approach designed to provide users with a seamless and efficient experience across a variety of tools and platforms. The methodology combines the strengths of a central User Management System and the RINNO Suite platform's iFrame technology to create a secure, cohesive, and efficient operational environment. By enabling seamless interaction between various tools, supporting smooth data exchange, and ensuring a unified user experience, it provides a robust foundation for managing and optimizing workflows in complex multi-tool ecosystems.

<u>User Management System</u>

As a building renovation project is a complex task involving various different stakeholders working consecutively or simultaneously, there was a need to consider these different roles in the project when using the platform. For this reason, a user management system was developed where the user has access to those specific tools relevant to the stage that they are working on. In order for a user to obtain access the RINNO Suite and the specific software tools, it is required to register in the platform. A registration page has been developed where the new user enters specific information in order to register to the Platform. A screenshot of this page is presented in Figure 3-1.

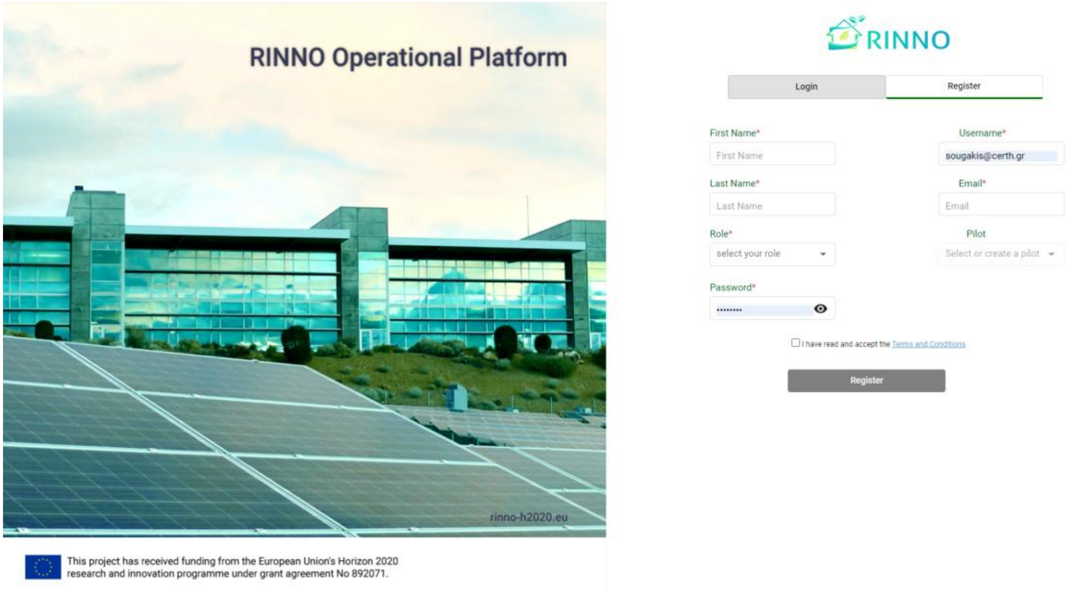

Figure 3-1: Homepage of the RINNO Platform

As seen in the above figure, apart from the personal (first and last name) and other common information (username, password and email), the user also needs to select the 'Pilot' and the 'Role'. The former determines the building that the user will be working on; the user may select one of the already developed pilots or create a new project (in case of a new project that has not been created yet). The 'Role' field determines the role of the user in the project and thereby the relevant access rights to the various tools. A number of different roles were developed based on the requirements of the various tools. These are presented in Figure 3-2 below along with the tools they have access to.

	Tool	User profile															
		Architect	Project owner	Design manager	Design team member	Design coordinator	Construction director	Construction site manager	Construction team member	Site supervisor	Site worker	Sub-contractor	Construction logistic manager	Warehouse manager	Energy Consultant	Occupant	Renovation Manager
WP4	On/Off site tool	X	X	X	X	X	X										
	E cockpit			X		X	X	X	X	X							
	E logistic							X	X	X			X	X			
	AR/VR tool							X	X	X	X	X					
	RRM	X	X	X	X	X	X	X	X	X	X	X					
WP3	Digital Twin	X	X	X	X	X									X		X
	INTEMA.building	X	X	X	X	X									X		X
	VERIFY	X	X	X	X	X									X		X
	TEA tool	X	X	X	X	X									X		X
	s-LCA	X	X	X	X	X									X		X
	Renovation Scenario DSS	X	X	X	X	X									X		X
	Job Scheduling Optimiser	X	X	X	X	X	X	X		X					X		X
WP5	Performance Dashboard		X							X							X
	3D Viewer		X							X						X	X
	Marketplace	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Social Colaboration	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 3-2: RINNO Suite Roles

The User Management System acts as the backbone for orchestrating user information and access rights across all integrated components. By maintaining centralized control over user data and permissions, the methodology ensures consistency, security, and streamlined operations throughout the ecosystem.

The User Management System is designed to manage comprehensive user information efficiently. It maintains a centralized database that includes personal details, roles, and access rights, ensuring that this data is consistent and up-to-date across all connected tools and platforms. This centralized approach eliminates the discrepancies and inefficiencies that can arise from maintaining multiple, disconnected databases, fostering a cohesive and reliable user management environment.

Access control is a critical aspect of this methodology, achieved through the use of user tokens for authentication and authorization. These tokens encapsulate crucial information regarding a user's roles and permissions, allowing integrated tools to verify access rights dynamically. The system ensures that access is granted or denied based on well-defined credentials and permissions, adhering to stringent security and compliance standards. This token-based approach not only enhances security but also simplifies the user experience by streamlining authentication processes across the integrated ecosystem.

Methodological approach for unified RINNO Suite

The RINNO Suite platform comprises various tools hosted by different providers. For this reason, a suitable methodological approach was developed in order to seamlessly integrate the multiple RINNO tools. This approach serves as the core environment for tool integration, employing iFrame technology to host diverse tools from various providers. This technology enables the embedding of one HTML document within another, allowing different tools to coexist and function cohesively within a single unified interface. Users can interact with multiple tools without the need to leave the RINNO Suite platform, thereby preserving a consistent and uninterrupted workflow. The iFrame approach also provides isolation between hosted tools, enhancing security by preventing unauthorized interactions between embedded applications. Additionally, the configuration of these iFrames can be customized to seamlessly align with the platform's interface, ensuring an intuitive and user-friendly experience

Another key aspect of the methodology is the facilitation of smooth data transfer between tools hosted on the RINNO Suite platform. Input data entered into one tool can be automatically shared with other tools as needed, eliminating the inefficiencies of manual data re-entry. Similarly, output data generated by one tool becomes readily accessible for use in other tools, fostering an interconnected and efficient environment. This seamless data transfer is achieved through the implementation of well-defined APIs and standardized data exchange protocols that ensure data integrity and consistency throughout the ecosystem.

The integration methodology delivers numerous significant benefits. A unified user experience minimizes the need for users to navigate multiple platforms and tools, enhancing productivity and reducing cognitive load. The central User Management System reinforces security and compliance by maintaining strict access control, safeguarding sensitive information, and ensuring adherence to organizational policies. Efficient workflows are achieved through the automation of data transfer between tools, reducing redundancy and streamlining processes. Furthermore, the use of iFrame technology offers modularity and flexibility, allowing new tools to be added or existing ones to be updated without disrupting the platform's functionality.

3.1 RINNO Suite Management

3.1.1 RINNO Planning and Design Assistant tools integration (WP3)

The various components of the RINNO Planning and Design Assistant were developed as stand-alone software tools within the Tasks of WP3. The status of the individual tools (interface, functionalities, workflow and user guide) is described in the respective Deliverables, namely

i. Deliverable 'D3.4 - Renovation Digital Twining tool and Scenarios definition (Final Version)'

ii. Deliverable 'D3.6 – RINNO Renovation Simulation and Assessment Toolbox (final version)'

iii. Deliverable 'D3.8 – RINNO Renovation Optimiser and Planner (final version)'.

Integration of the RPDA tools was conducted in four distinctive stages. The first stage involved the interconnection and communication of the tools with each other after they were first developed (as stand-alone applications). This process took place prior the development of the RINNO suite and aimed at establishing a preliminary connection of the tools. The second stage involved integrating the tools to the RINNO Suite to form the RINNO Planning and Design Assistant component of the Platform. The interconnection of the tools in this second stage followed the same general interconnection process established in the previous stage but with specific changes in the exchange of critical information. Once the RPDA tools were integrated to the RINNO Suite, the next stage included specific actions to establish the communication of the outcome of the RPDA tools (WP3) (the preliminary sequence of works of the selected renovation scenario) to the RRM (WP4) for conducting the detailed day-to-day planning and the renovation. In this stage the information flow between the design phase and the construction phase of the renovation is achieved. Finally, the last stage involves connecting the output of the JSO to the RINNO Building Lifecycle Renovation Manager (WP5) to deliver necessary data the Renovation Roadmap, ensuring seamless integration and enabling the concept of Building Renovation Passports to support deep renovation in stages.

3.1.1.1 Stage 1: Interconnection of the RPDA tools

The general approach on integrating the tools of the RINNO Simulation and Assessment Toolbox and the RINNO Optimiser and Planner to allow for the seamless communication and flow of information between them was defined and described in the relevant Deliverables D3.6 and D3.8. A Pilot ID for each building was defined and taken into consideration when sharing information and data between the various tools. The use of a unique Pilot ID, Pilot Name and Scenario ID for each building and respective scenario ensures that results/data for the same building are shared between the tools. In the first stage of development this Pilot ID was generated by VERIFY and then communicated with the rest of the RPDA components (as described in Deliverable D3.6).

The process of connecting the various tools was described in Deliverables D3.6 and D3.8 and presented here to ensure completeness. The connection of the tools was completed in the following order:

1. **Interconnection of the INTEMA.building and VERIFY**. The energy analysis of the building is conducted first in INTEMA.building where the user enters a Pilot Name as well as the relevant ID of the scenario examined to assess the energy performance and generate the energy related KPIs for that scenario. In addition, the user also provides the renovation scenario description in INTEMA. Next, the user proceeds with the LCA/LCC analysis in VERIFY. As mentioned previously, at this stage of the development VERIFY holds a central role in the RPDA process where it not only conducts the LCA/LCC analysis but it also communicates to the rest of the tools to collect and distribute necessary data. The first connection is established between VERIFY and INTEMA.building in order for VERIFY to: i) gather the energy related KPIs and the renovation scenarios description from INTEMA.building , ii) collect energy timeseries related to the operational phase of the building generated by INTEMA.building. The former is stored and then forwarded to the rest of the tools. The latter is used to conduct the LCA/LCC analysis. Communication with INTEMA.building is established via entering the same Pilot Name (which was used earlier in INTEMA.building) and the specific Scenario ID through VERIFY's GUI and pressing the corresponding button to retrieve the data sending an HTTP request. INTEMA.building recognizes the incoming scenario from VERIFY and returns the relevant information (KPIs, scenario description and timeseries) bundled in a JSON file which is parsed by VERIFY (Figure 3-3). Following the implementation of all necessary adjustments, a test was conducted to confirm that all steps were successfully completed (Table 3-1)

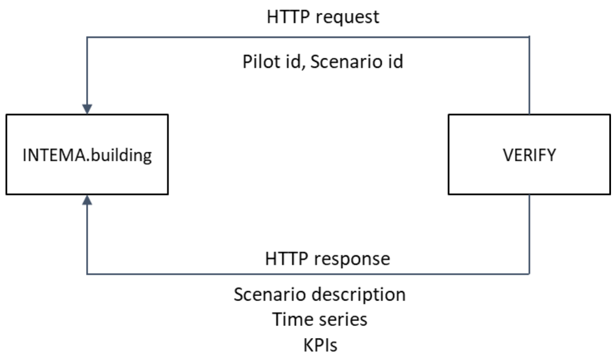

Figure 3-3: Connection between INTEMA.building and VERIFY

Table 3-1: Test conducted to confirm the communication between INTEMA.building and VERIFY

Test ID	Test Name	Objective	Procedure	Expected result	Time conducted
1	Communication between INTEMA.building and VERIFY	Testing the HTTP request and response between the two tools for VERIFY to retrieve the energy KPIs and scenarios description	A building, including a scenario, was designed in INTEMA.building using some pilot and scenario id. The INTEMA.building simulation was performed to calculate the energy KPIs. The building along its scenario was also created in VERIFY using the same pilot and scenario id as in INTEMA.building. Timeseries and KPIs requested thought the front end of VERIFY.	INTEMA sending energy KPIs, timeseries and scenarios description to VERIFY. VERIFY stores the received data in its database.	M34

2. **Connection of the VERIFY tool with the TEA tool**. Having finished the LCA/LCC analysis the user may create in VERIFY tool a JSON file with the description of the renovation scenarios and the pilot ID which is stored in a dedicated SFTP server in order for this to be retrieved by the TEA tool. This step serves the purpose of communicating the renovation scenarios description to the TEA user to conduct the analysis. It is only relevant (and therefore optional) if the TEA user is different to the VERIFY user. The name of the JSON file includes the Pilot ID and the Scenario ID. Once the user of the TEA tool receives this information, then they may proceed with the analysis to estimate the levels of disruption and waste produced. When the analysis is finished the TEA tool saves the results (namely a JSON file with the relevant user disruption / waste management KPIs and the Excel files containing all the calculations from the TEA tool) in the SFTP server (Figure 3-4). Once all necessary actions were implemented, a test was carried to confirm communication between VERIFY and the TEA tool was successful (Table 3-2).

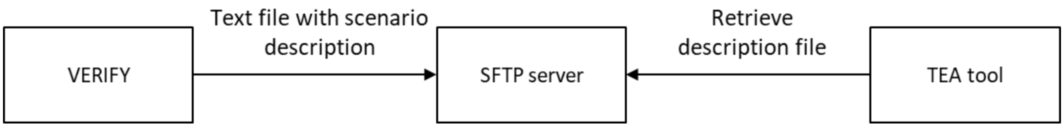

Figure 3-4: Connection between VERIFY and TEA tool

Table 3-2: Test conducted to confirm the communication between VERIFY and the TEA tool

Test ID	Test Name	Objective	Procedure	Expected result	Time conducted
1	Communication between VERIFY and the TEA tool	Testing the communication between the VERIFY tool and the TEA tool through the sftp server	Before the execution of this test the steps of VERIFY-INTEMA.building communication procedure were conducted. After the scenario description was successfully stored in VERIFY's database, the file was uploaded in the SFTP server through the front end of VERIFY, by clicking the corresponding button which initiates the process in the back end.	VERIFY uploading the renovation scenarios description to the sftp server	M39

3. **Interconnection of the VERIFY tool with the Renovation Scenario DSS**. Upon the completion of the LCA/LCC analysis, VERIFY also generates the environmental and cost/financial KPIs and sends them to the Renovation scenario DSS along with the energy KPIs and the scenarios description provided by INTEMA.building. The user forwards the KPIs and the scenarios description in JSON format to the DSS using VERIFY's GUI. Communication between these two tools is achieved through DSS's API. The KPIs along with the Pilot ID (generated in VERIFY) as well as the Scenario ID are compiled into a JSON file and sent to the Renovation Scenario DSS using the HTTP protocol. The DSS then generates a new entry in its database for this Pilot ID (Figure 3-5). The test conducted to confirm the successful interconnection between VERIFY

and the Renovation Scenario DSS is presented in Table 3-3.

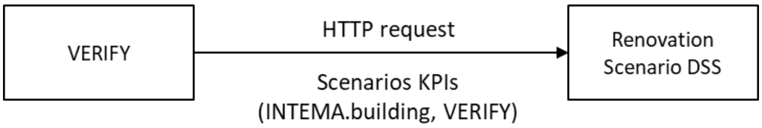

Figure 3-5:Connection between VERIFY and Renovation Scenario DSS

Table 3-3: Test conducted to confirm the communication between VERIFY and the Renovation Scenario DSS

Test ID	Test Name	Objective	Procedure	Expected result	Time conducted
1	Communication between VERIFY and Renovation Scenario DSS	Testing the HTTP request for VERIFY to send the scenarios description and the energy, environmental and cost KPIs to the Renovation Scenario DSS	Before the execution of this test the steps of VERIFY-INTEMA.building communication procedure were conducted, since VERIFY is responsible for also sending the energy KPIs calculated by INTEMA.building. After all the KPIs were successfully collected, the process was initiated in the front end of VERIFY. The corresponding button was clicked which initiates the process in the back end.	VERIFY sending the energy, environmental and cost KPIs and the renovation scenarios description to the DSS	M30

4. **Interconnection of the TEA tool with the RINNO Optimiser and Planner**. This involves the connection of the TEA tool with both the Renovation Scenario DSS and the Job Scheduling Optimiser. The communication with these tools is done through an intermediate SFTP server where the TEA tool uploads: i) the KPIs on user disruption and waste management and ii) the excel files of the analysis containing the jobs for each renovation scenario investigated and the respective job specifications (cost, duration, workers needed). The KPIs are retrieved from the SFTP server and parsed by the Renovation Scenario DSS. Similarly, the excel files are parsed by the Job Scheduling Optimiser through the SFTP server and used for planning the optimum sequence of works. The JSO selects the appropriate file with the relevant job specifications according to the Pilot ID (obtained through the RINNO Platform) and the Scenario ID (provided by the user through the GUI) and conducts the planning of works (Figure

3-6). Following the implementation of all necessary adjustments, a test was conducted to confirm that all steps were successfully completed (Table 3-4)

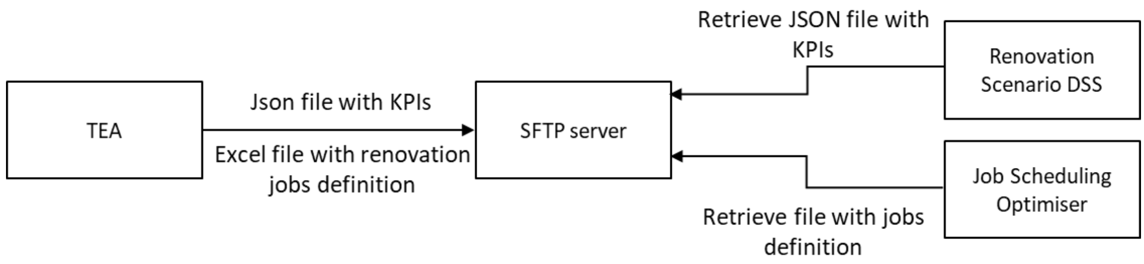

Figure 3-6: Connection between TEA tool and the RINNO optimiser and Planner components

Table 3-4: Test conducted to confirm the communication between VERIFY and the Renovation Scenario DSS

Test ID	Test Name	Objective	Procedure	Expected result	Time conducted
1	Communication between TEA tool and RINNO Optimiser and Planner	Testing that the TEA tool is saving the KPIs and excel files in the SFTP sevrver and the DSS and JSO successfully retrieve them	1 TEA: The TEA tool after completing the analysis saves the JSON with the waste management and user disruption KPIs and the excel files with the calculations to the SFTP server. The tool also provides a results Excel file, which is saved locally on the computer. 2. After the TEA tool has uploaded the files in the SFTP server, retrieves the KPI data (e.g., environmental, energy, financial, user disruption indicators) for selected scenarios via backend services 3. JSO: After the TEA tool has uploaded the excel files on the SFTP server, the file was retrieved in JSO by using the corresponding GUI elements where the pilot and scenario id of interest are provided.	1. TEA tool saving the user disruption and waste management KPIs as well as the excel file with the job specifications to the SFTP server. In addition, xlsx file saved on the local computer environment. 2. DSS able to retrieve the KPIs 3. JSO able to retrieve the excel file	M36

During the course of Task 6.1 this approach was updated to allow the workflow and smooth transition between the software tools of not only the RPDA (Stage 2 of integration) which focuses on the design stage of the renovation but also with the RINNO Retrofitting Manager (RRM) (Stage 3 of integration) which deals with the installation/construction phase. For this, it was decided that the definition of the Pilot ID and Pilot Name should be done centrally in the Platform via the User Management System which handles the registration process.

3.1.1.2 Stage 2: Integration of RPDA tools to the RINNO Suite

This stage involved connecting the RPDA tools to the RINNO Platform enabling i) the central management of the users, providing access to certain tools according to the user roles, ii) simplification of processes and minimising user inputs (eliminating potential human error) and iii) interconnection with the RINNO Renovation Manager and the tools of the RINNO Building Lifecycle Renovation Manager.

This step involved the connection of the different tools to the user management system of the RINNO Suite in order to retrieve the necessary input for the communications between them. During the user registration process and the creation of a new renovation case, the user enters a Pilot Name and the RINNO Suite generates a unique Pilot ID for this case. This Pilot ID and Pilot Name are then used by all the tools to exchange information. As the generation of the unique Pilot ID was previously done by VERIFY in Stage 1, specific changes were required to be done in order to re-establish the interconnection of the different software tools as described below:

- INTEMA building: The Pilot Name required when creating a new case is now retrieved by the RINNO Suite - not entered manually by the user as was the case in Stage 1;
- The functionality of the VERIFY tool to generate the Pilot ID is disabled. The Pilot ID received by the RINNO Platform along with the Pilot Name and cannot be changed by the user. This eliminates potential communication errors due to mistakes in the manual entry of such information.
- The Renovation Scenario DSS receives and automatically displays the name of the renovation case which the user has access to. This ensures that the KPIs for the correct case are loaded by the tool and that the user does not accidentally chose a different case.
- Similarly, the Job Scheduling Optimiser receives and automatically displays the name of the renovation case which the user has access to.

The developments on the relevant tools and the establishment of the new connection process were conducted in a similar manner as in the first integration stage. Again, relevant tests were conducted to confirm that communication and seamless information exchange was established as shown in Table 3-5 below.

Table 3-5: Series of tests conducted to ensure the RPDA tools were integrated to the RINNO Suite

Test Id	Test Name	Objective	Procedure	Expected Result	Time Conducted
1	INTEMA.building authentication to RINNO Suite	Testing the authentication of INTEMA.building Testing the ability to retrieve Pilot ID from the RINNO Suite	After successfully adding a user in the RINNO suite, and, hence in INTEMA.building (using the related exposed endpoints): 1) Authentication and Data retrieval takes place when user logs in the RINNO suite and clicks the button to INTEMA.building. The authentication is implemented via JWT tokens in which the username, mail of the user are encoded. The Pilot ID and Pilot Name are then retrieved via an API request in /getUserBasicInfo endpoint	Access to INTEMA.building once logging to the RINNO Suite. In addition, INTEMA.building will receive the relevant Pilot ID from the RINNO Suite. Any results refer to that particular building	M42
2	VERIFY authentication to RINNO Suite	Testing the authentication of VERIFY Testing ability to retrieve Pilot ID from the RINNO Suite	After successfully adding a user in the RINNO suite, and, hence in VERIFY (using the related exposed endpoints): 1) Authentication: a user logged in the RINNO suite, then clicked the link to VERIFY. 2) Retrieval: a user visited the form of VERIFY where a new building is created (in that form the pilot ID and name are expected to be displayed).	Access to VERIFY once logging to the RINNO Suite. In addition, VERIFY will receive the relevant Pilot ID from the RINNO Suite. Any results refer to that particular building	M42
3	Renovation Scenario DSS	Testing the authentication of Renovation Scenario DSS Testing ability to retrieve Pilot ID from the RINNO Suite	1) Authentication: a user logged into the RINNO Suite, then accessed the Renovation Scenario DSS via the main interface. 2) Retrieval: upon accessing the Renovation Scenario DSS, the component automatically retrieved the associated pilot ID based on the logged-in user.	Access to Renovation Scenario DSS once logging to the RINNO Suite. In addition, Renovation Scenario DSS will receive the relevant Pilot ID from the RINNO Suite.	M40

			The pilot's data was displayed, and all further actions referred to that particular building	Any results refer to that particular building	
4	Job Scheduling Optimiser	Testing the authentication of JSO Testing ability to retrieve Pilot ID from the RINNO Suite	After successfully adding a user in the RINNO suite, and, hence in JSO (using the related exposed endpoints): 1) Authentication: a user logged in the RINNO suite, then clicked the link to JSO. 2) Retrieval: a user visited the form of JSO where a renovation scenario can be retrieved from the SFTP server (in that form the pilot ID is expected to be displayed).	Access to JSO once logging to the RINNO Suite. In addition, JSO will receive the relevant Pilot ID from the RINNO Suite. Any results refer to that particular building	M42
5	Communication of all RPDA tools	Testing that all tools are communicating and a complete building analysis can be conducted	A building with two renovation scenarios was created. This was analysed in all tools to ensure that the process is completed successfuly	Performing a full analysis on a case study. All results are used by the DSS to select the scenario and the JSO optimizes the sequence of works	M43

Having implemented these changes, the process of creating a new case to be examined through the RINNO Planning and Design Assistant is as follows:

- Step 1: The user completes the registration in the RINNO Suite for a new building using an appropriate role for the design stage of the building (architect, energy consultant etc.). The user defines the name for that building and a unique ID is automatically generated by the User Management System which is used for the communication between the RPDA tools
- Step 2: The user may conduct the analysis in the Digital Twin tool for the preliminary energy analysis. This enables the user to assess several renovation measures quickly and form specific renovation scenarios which are then investigated in detail in the subsequent steps. As the Digital Twin tool is only applicable in the countries of the four demo buildings, namely France, Denmark, Greece and Poland and does not have a general use as the rest of the RPDA tools do (irrespective of the country where the building under investigation is located), this step is optional. For this reason, the Digital Twin tool does not receive information on the Pilot ID and Pilot Name from the User Management System as it does not exchange this information with the rest of the tools.
- Step 3: The user may conduct the detailed energy analysis using INTEMA.building.

When starting the analysis in the INTEMA.building tool there are three fields which require input in order to define the case that will be examined (Figure 3-7):

i. **Pilot name**. This is already filled in with the pilot name that was defined by the user in the platform during the registration. To do so, the tool retrieves the Pilot ID and Pilot name from the RINNO Suite in the back-end and presents the Pilot name to the user.

ii. **Scenario**. The user may fill in 'baseline' or a numeric value for the scenario examined (i.e scenario 2, 3 etc.) depending on whether the existing condition (baseline) or a renovation scenario is examined. When the analysis of the baseline and a renovation scenario are finished the energy related KPIs for that particular scenario are calculated.

iii. **Scenarios description**. The user may use this field to include a brief description of the renovation measures examined. This information will be presented later in the DSS when the optimum scenario is selected. This input is optional.

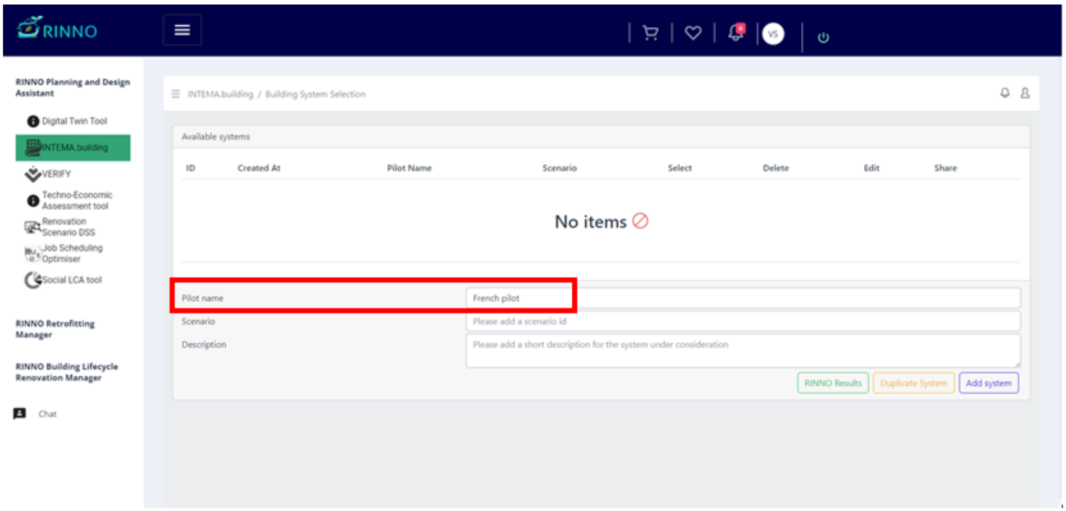

Figure 3-7: Instance from the INTEMA.building tool with predefined Pilot Name

- Step 4: Having finished the energy analysis, the user may then proceed to the VERIFY tool for the LCA/LCC analysis of the renovation scenarios. When developing the Project Setup for the renovation scenario to be examined (as described in Deliverable D3.6), the Pilot Name and the Pilot ID are already filled in according to the registration of the particular user (Figure 3-8). This ensures that information for the correct building is exchanged between INTEMA.building and VERIFY.

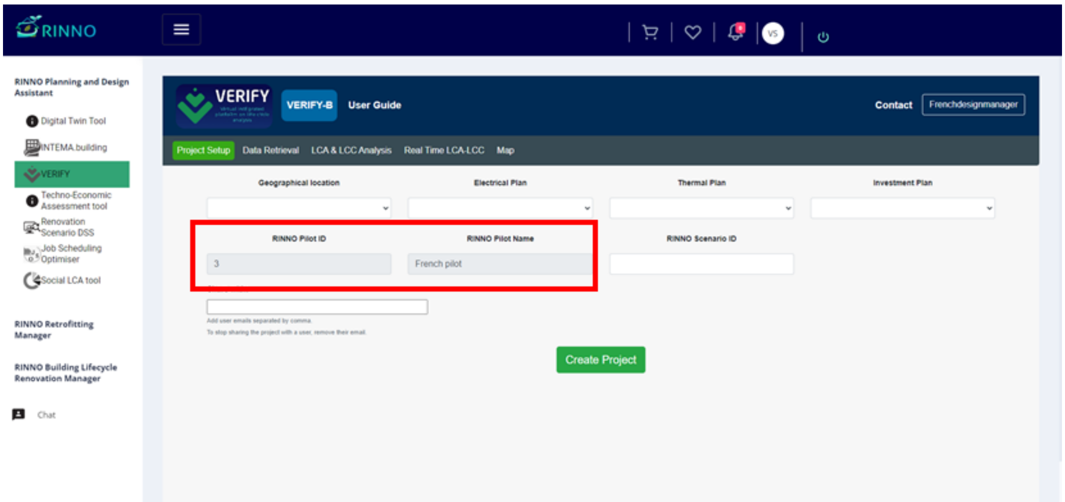

Figure 3-8: Instance from the VERIFY too with predefined Pilot Name and Pilot id

Step 5: The user may then proceed to conduct the analysis in the TEA tool to calculate the user disruption and waste management KPIs. As the TEA tool is desktop based, it is not integrated to the RINNO Suite. The user may conduct the analysis using the same Pilot Name – Scenario ID as with the rest of the RPDA tools and the results will be saved in a SFTP server with a name that is readable from the Renovation Scenario DSS and the Job Scheduling Optimiser to obtain the KPIs and the excel file with the jobs specifications (Figure 3-9).

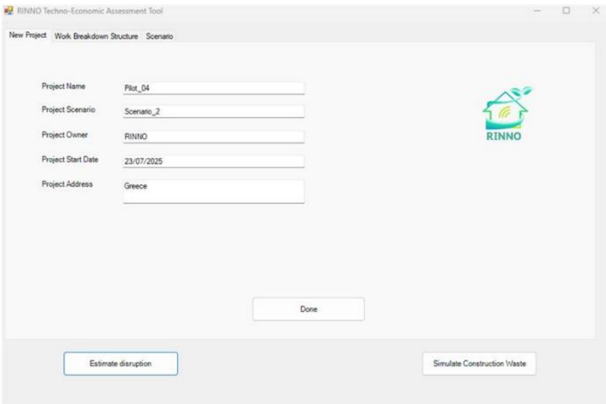

Figure 3-9: GUI of the TEA tool where the user defines the Pilot Name and Scenario ID

Step 6: Once the analysis on i) energy performance, ii) environmental impact and cost during the lifecycle of the building and iii) user disruption and waste management with the tools of the RINNO Simulation and Assessment Toolbox is finalised, the selection of the best renovation scenario is then conducted with the Renovation Scenario DSS tool. Similar to the rest of the tools, the Renovation Scenario DSS uses the Pilot ID to retrieve information and ensure that the scenarios which are loaded and compared refer to the building under investigation. This is taking place in the back-end environment, while the user only sees the Pilot Name in the relevant field (Figure 3-10). This is already pre-filled and the user does not have the option to change the building examined.

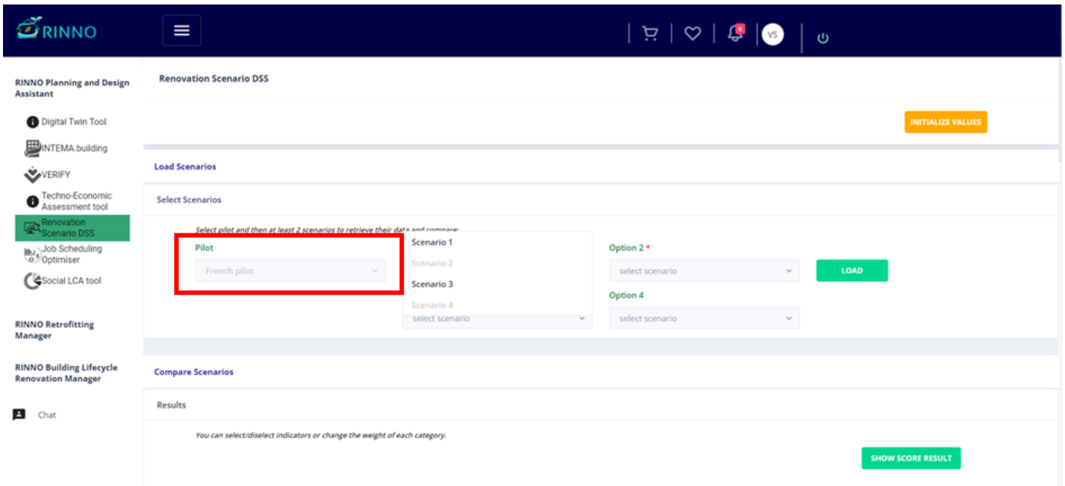

Figure 3-10: Instance from the Renovation Scenario DSS with predefined Pilot

Step 7: In the final step, the optimum sequence of works is derived with the use of the Job Scheduling Optimiser. The process for doing so is described in detail in Deliverable D3.8. When the relevant scenario is loaded, the Pilot Name and the Pilot ID are already filled-in and the user does not have the option to change them as shown in Figure 3-11. Therefore, the user is able to load only the activities for the specific building when running the optimum workflow analysis.

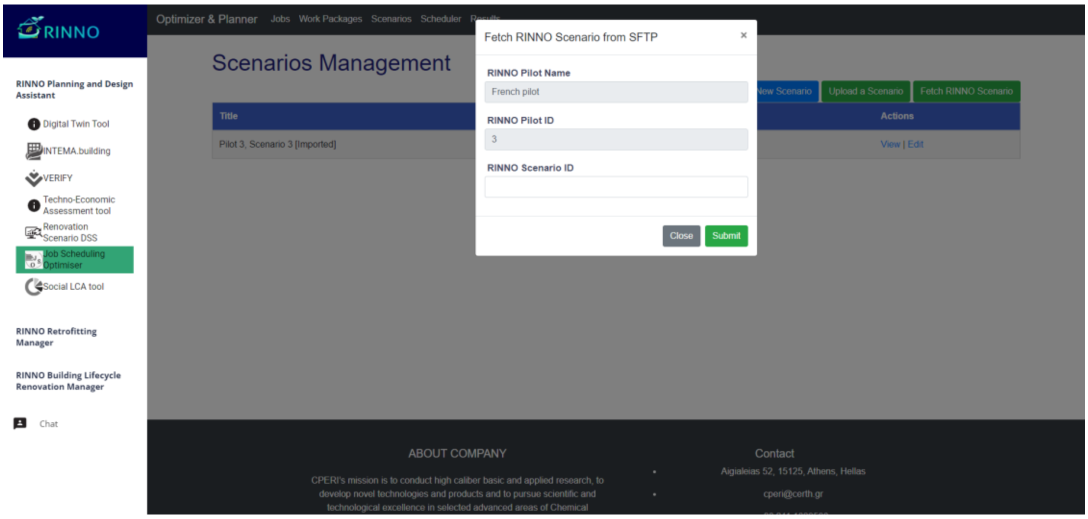

Figure 3-11: Instance from the Job Scheduling Optimiser with predefined Pilot Name and Pilot id

The steps followed for conducting the multi-performance analysis of the renovation scenarios at the design stage with the tools of the RPDA that were described above are presented schematically in Figure 3-12 below.

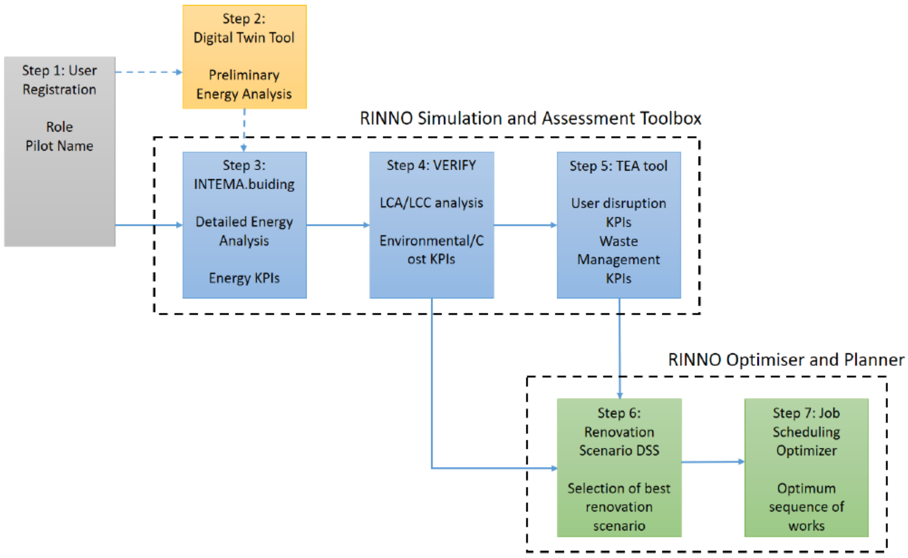

Figure 3-12: Schematic representation of the steps followed and the interconnections between the tools of the RPDA

The figure above explains the workflow of the RINNO design-stage tools. After user registration, the process runs from preliminary energy analysis (Digital Twin) to detailed assessments (INTEMA.building, VERIFY, TEA). Results feed into the Renovation Scenario DSS for selecting the best option, followed by the Job Scheduling Optimizer to generate the optimal work plan.

3.1.1.3 Stage 3 – Interconnection of the RPDA to the RRM

Having finished the analysis and generated the renovation scenario, this may then be sent to the RRM in order to continue the renovation works scheduling at the construction site. After conducting the scheduling, the user may proceed to store the generated schedule and set the renovation scenario as the 'best' (Figure 3-13). Since a user may manage multiple renovation scenarios for the same pilot, this is necessary to ensure the correct scenario is sent to the RRM. Once a renovation scenario is marked as 'best', the RRM can request its scheduling data. This is done via an HTTP GET request. Specifically, RRM requests the best scenario for a given pilot, and JSO responds with the corresponding scheduling data stored in its database. The request is sent with token-based Bearer Authentication so that JSO can verify the sender.

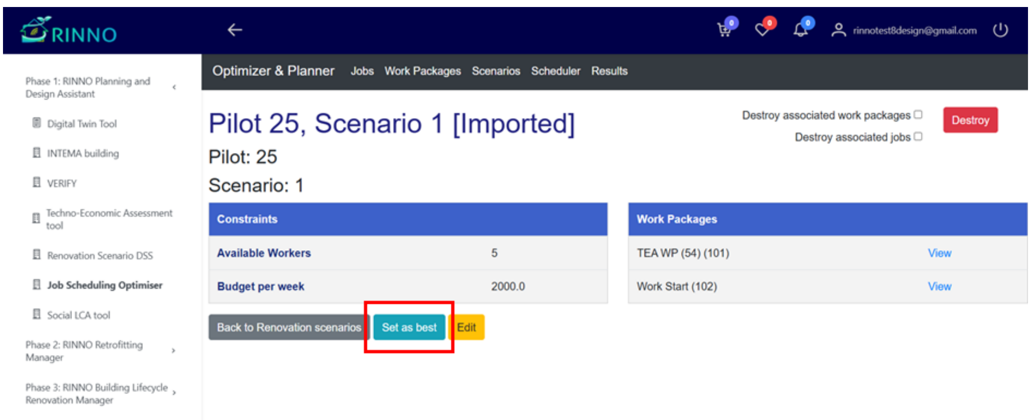

Figure 3-13: View of the JSO GUI where the user marks the scenario to be sent to the RRM

Table 3-6: Test conducted to confirm the interconnection between JSO and the RINNO Retrofitting Manager

Test ID	Test Name	Objective	Procedure	Expected result	Time conducted
1	Communication between JSO and the RRM	Testing the communication between the JSO tool and the RINNO Retrofitting Manager. The RRM should receive the optimum renovation scenario by the JSO	Before this test, it is required that a renovation scenario was scheduled, stored and marked as "best" in JSO. Using the endpoint and JWT token provided by the JSO developers to the RRM developers, RRM programmatically performed a request in order to retrieve the optimum scenario	The user may set a specific renovation scenario as best. Once this is done this should appear on the RRM for further processing on site	M42

3.1.1.4 Stage 4 – Interconnection of the RPDA to the RINNO Building Lifecycle Renovation Manager

JSO is also responsible for delivering the Renovation Roadmap to the RINNO Building Lifecycle Renovation Manager, where it is graphically visualized. The generation of the Renovation Roadmap involves other tools of the RPDA which provide the necessary data for this process. This data includes: i) the set of jobs to be scheduled (i.e., renovation interventions), provided by the TEA tool, ii) the load reductions achieved by each intervention type, calculated by INTEMA.building and provided to VERIFY, and, iii) the primary energy, CO_2 emissions, and cost savings associated with each intervention, calculated by VERIFY upon request from JSO.

Once all required data has been collected, JSO generates the Renovation Roadmap, as detailed in Deliverable 5.7 - Standardization of RINNO's Building Renovation Passports and Logbook. upon request. This request is initiated by the RINNO Building Lifecycle Renovation Manager via an HTTP GET request to JSO, which includes the relevant pilot and scenario identifiers. Upon receiving the request, JSO constructs the Renovation Roadmap, using the collected data, and returns it in the response. This request also makes use of the token-based Bearer authentication so that JSO responds only to valid request senders.

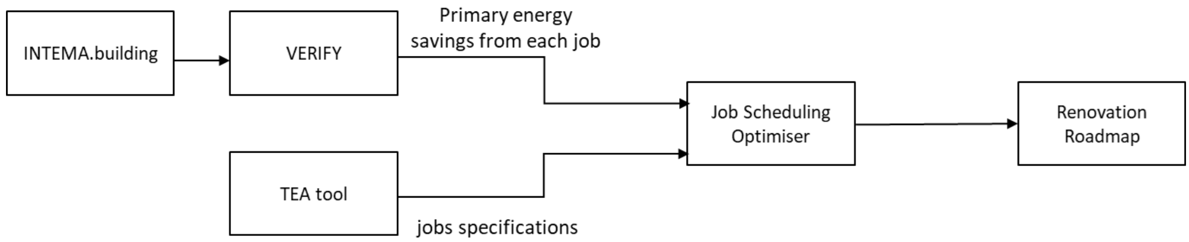

Figure 3-14: Connection between Job Scheduling Optimiser (WP3) and the Renovation Roadmap (WP5)

Table 3-7: Test conducted to confirm the interconnection between JSO and the Renovation Roadmap

Test ID	Test Name	Objective	Procedure	Expected result	Time conducted
1	Information exchange between INTEMA.building and VERIFY	VERIFY obtains all relevant information on the energy savings per job from INTEMA.building	Repeating the test conducted at an earlier stage for the communication between VERIFY and INTEMA.building.	INTEMA.building conducts the energy analysis of a scenario. In addition to the rest of the information sent to VERIFY (Energy KPIs, timeseries, renovation scenario description), INTEMA also sends a breakdown of the energy savings achieved by each renovation measure	M58
2	Information exchange between VERIFY and and JSO	JSO Obtaining relevant information from VERIFY	JSO automatically requests the savings data from VERIFY upon a renovation scenario creation. To perform this test, first the steps of the previous test were conducted. Then, a renovation scenario was created which was assigned the pilot and scenario id that were used in INTEMA.building and VERIFY	VERIFY sends the primary energy, CO_2 emissions, and cost savings associated with each intervention to the JSO	M58
3	Communication and information exchange between JSO and RINNO Building Lifecycle Renovation Manager	Testing the communication between the JSO tool and the Renovation Roadmap	To proceed with that test, the steps of the previous test were conducted. Then, a request from the RINNO Lifecycle Renovation Manager was performed to the endpoint (including a JWT) provided by the JSO developers. To proceed with that test, the steps of the previous test were conducted.	JSO generates the Renovation Roadmap and sends it to the Building Lifecycle Renovation Manager to display it to the user	M59

3.1.2 RINNO Retrofitting Manager Integration (WP4)

The Components Integration and Acceptance Tests for the digital tools used in the construction and renovation phase of buildings focus on ensuring that the different modules of the RINNO Retrofitting Manager, such as Offsite tool, Planning, AR Environment, the Cockpit, and E-logistics, work seamlessly together to support efficient and optimized project delivery.

The integration testing begins with the Offsite module, where the connection between prefabrication processes and the central planning system is evaluated. It is crucial that data about prefabricated components, their production progress, and delivery schedules are correctly synchronized with the scheduling optimizer. This ensures that what is designed and produced offsite is available on time and aligns with the overall construction timeline. The acceptance phase verifies that prefabricated elements match their design specifications and can be integrated on-site without delays or mismatches.

For the Logistics and E-logistics systems, integration tests validate whether supplier information, transport planning, and material availability are correctly exchanged with the job scheduling optimizer. The data flows need to be accurate and consistent so that costs, delivery times, and storage capacities are properly represented in the construction plan. The acceptance tests confirm that logistics operations in practice—such as delivery times, on-site storage, and handling—match the optimized plan and that the digital logistics models truly minimize disruptions on site.

The Job Scheduling Optimizer (JSO) itself is tested by integrating it with real project data coming from logistics, workforce planning, and site management. During integration, the tool's ability to generate optimized schedules that take into account cost minimization, duration reduction, and user-defined constraints is validated. The acceptance phase ensures that the produced schedules are not only mathematically optimized but also practical, realistic, and resilient to unexpected changes such as material delays or sudden workforce shortages.

The AR Environment plays a central role in supporting training and onsite assistance during the construction and renovation process. In the integration phase, tests confirm that planning data, BIM models, and scheduling outputs can be correctly adapted for use in augmented reality scenarios that provide real-time guidance to workers on-site as well as structured training sessions offsite. The acceptance phase focuses on verifying that end-users such as engineers, site managers, and construction workers can effectively use the AR tools for hands-on training, operational support, and skill development. This ensures that the system not only functions technically but also delivers practical value by improving workforce readiness, reducing errors during execution, and enhancing decision-making through immersive and accessible training environments.

The Cockpit, as the central monitoring and control dashboard, undergoes testing to ensure that it consolidates all relevant data streams from Offsite, Logistics, Planning, and AR/VR environments. Integration testing verifies that KPIs, alerts, and progress reports remain consistent across modules. During acceptance, decision-makers evaluate whether the Cockpit provides clear, reliable, and actionable insights for project steering, making it a practical tool for risk management and progress monitoring.

The overall purpose of these tests is to guarantee that the system functions as an integrated whole rather than as isolated components. The testing ensures data consistency across all modules, validates that optimization algorithms reflect real-world conditions, and confirms interoperability with existing construction management systems and e-logistics platforms. Most importantly, the acceptance tests assess whether the tools meet end-user expectations by delivering reliable schedules, accurate logistics coordination, realistic simulations, and intuitive monitoring dashboards.

3.1.3 RINNO Building Lifecycle Renovation Manager Integration (WP5)

The various components of the RINNO Building Lifecycle Renovation Manager were developed as stand-alone software tools within the Tasks of WP5. The status of the individual tools (interface, functionalities, workflow and user guide) is described in the respective Deliverables, namely:

i. D5.2 'RINNO Renovation, Validation & Benchmarking tool – Performance Dashboard'
ii. D5.4 'Multi-Purpose IoT- Enabled Building Monitoring (Final Version)'
iii. D5.6 'Renovation Marketplace and Social Collaboration Platform (Final Version)'
iv. D5.7 'Report about Standardization of RINNO's Building Renovation Passports and Logbook'
v. D5.8 'Ricardian Contracts for Automated and Secure Transactions'

The integration between the Building Renovation Roadmap, the Building Logbook (consisting of Building Monitoring System, the Sensor-Enabled Building Model and the Static Building Information section), the Marketplace, and the Online Contracts leverages a robust exchange of information to enable seamless operation, effective decision-making, and streamlined workflows. The following details describe the interconnections among the tools, emphasizing the flow of information and their functional dependencies.

1. Integration of the Renovation Roadmap

The renovation roadmap is integrated into the digital platform as a step-by-step visual and analytical tool that guides users through different renovation strategies.

It begins with a baseline model of the building. The baseline includes key indicators such as primary energy use in kilowatt-hours, annual operating cost in euros, and CO_2 emissions in kilograms. This serves as the reference point before any interventions are applied.

Figure 3-15: Renovation Roadmap illustrating baseline performance and stepwise implementation of renovation measures, with corresponding impacts on energy demand, costs, and CO_2 emissions

The roadmap then develops through sequential steps. Each step includes specific renovation measures, for example wall insulation, photovoltaic systems, window replacement, ceiling insulation, water storage, or HVAC replacement. After each step, the platform updates and displays the expected performance outcomes in terms of energy demand, cost savings, emissions reductions, and required capital expenditure.

Two different renovation roadmaps can be created and compared. In the first roadmap, the sequence begins with wall insulation and façade photovoltaic installation, followed by ceiling insulation, and later floor insulation and HVAC replacement. In the second roadmap, the sequence begins with ceiling insulation and water storage before moving to wall insulation and façade photovoltaic systems, and then the remaining measures. This comparison allows users to evaluate how different renovation sequences affect results.

For each roadmap, the platform provides a consolidated summary that shows the total capital expenditure, the total primary energy demand after all measures, the operational cost, the total CO_2 emissions, and calculated ratios that reflect the cost-benefit balance.

To support understanding, the platform includes a simple icon legend for energy, costs, CO_2, and investment. There is also a function to add building data, meaning the roadmaps can be generated dynamically based on the specific input from a homeowner, engineer, or policymaker.

Data flows begin with the pilot buildings where sensors are installed. These sensors continuously monitor variables such as energy consumption, indoor climate conditions, and possibly equipment performance. The raw data collected from the buildings is transmitted into the platform’s database.

The Planning and Design Assistant, which is a decision-support tool, accesses this database to use the real-world measurements as input for simulations and modeling. This ensures that the renovation scenarios and roadmaps are grounded in actual building performance rather than just theoretical assumptions.

Therefore, the renovation roadmap is presented in the platform as an interactive decision-support system. It starts from the baseline, moves through staged interventions, calculates the results after each step, and finally provides aggregated outcomes for comparison across multiple strategies. This enables stakeholders to explore different pathways, balance investment and savings, and make informed renovation decisions.

2. Integration of the Building Monitoring System

The Performance Dashboard is used to compare expected, baseline, and actual performance of the building. It consolidates energy-related data such as electricity demand, natural gas demand, photovoltaic production, and overall primary energy demand. Each indicator is presented in three columns: baseline, expected, and actual. This makes it possible to track whether the building is performing as designed or whether deviations exist. For example, the dashboard shows expected versus actual electricity demand or photovoltaic generation, highlighting performance gaps. In this way, the dashboard acts as a benchmarking and evaluation tool that ties simulation-based expectations with real sensor-based data.

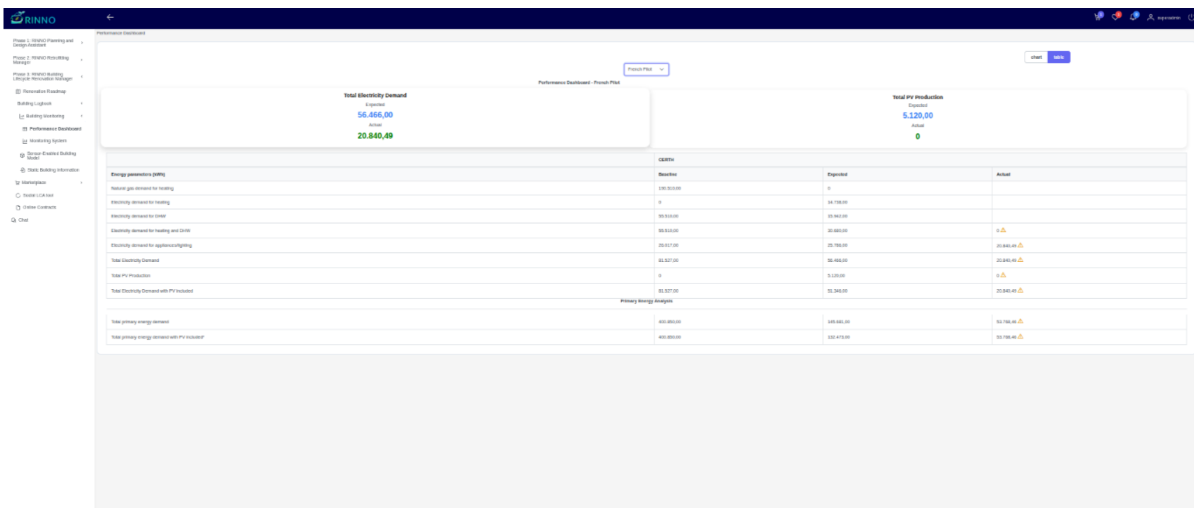

Figure 3-16: Performance Dashboard displaying expected and actual energy demand and production values after renovation, enabling validation of renovation outcomes

Figure 3-17: Monitoring System user interface showing real-time indoor and outdoor measurements alongside energy consumption and power factor time-series, enabling detailed analysis of building performance

The Monitoring System complements the dashboard by presenting continuous, real-time data streams from the building's sensors. It includes time series plots of different variables such as temperature, humidity, energy use, CO_2 levels, or equipment activity. These graphs allow the operator to follow the building's dynamics across time and detect anomalies or operational inefficiencies. On the right side, it also displays live sensor readings and indoor comfort indicators, making it possible to assess conditions easily.

Data interconnection works as follows:

- Sensors installed in the building collect raw data on energy consumption, indoor environmental quality, and system operation.
- This data is transmitted into the platform where it is processed and stored.
- The Performance Dashboard aggregates the processed data, compares it against expected and baseline scenarios, and presents the results as key performance indicators.
- The Monitoring System presents the same data in a more detailed time series format, enabling operational monitoring, fault detection, and occupant comfort assessment.

Together, both tools create a feedback loop: the Monitoring System provides granular real-time data, while the Performance Dashboard summarizes it for higher-level decision-making and comparison with design targets.

Thus, the Building Monitoring System integrates both high-level performance evaluation and detailed real-time monitoring, ensuring that renovation measures and building operation can be validated, optimized, and continuously improved.

3. Integration of the Sensor-Enabled Model with BIM Models and Notifications

The Sensor-Enabled Model combines the Building Information Modeling (BIM) environment and the Static Building Information with real-time sensor data, creating a digital twin of the monitored building that provides an accurate virtual representation of the building's current conditions. This model includes detailed information about the physical structure, installed devices, and their operational status.

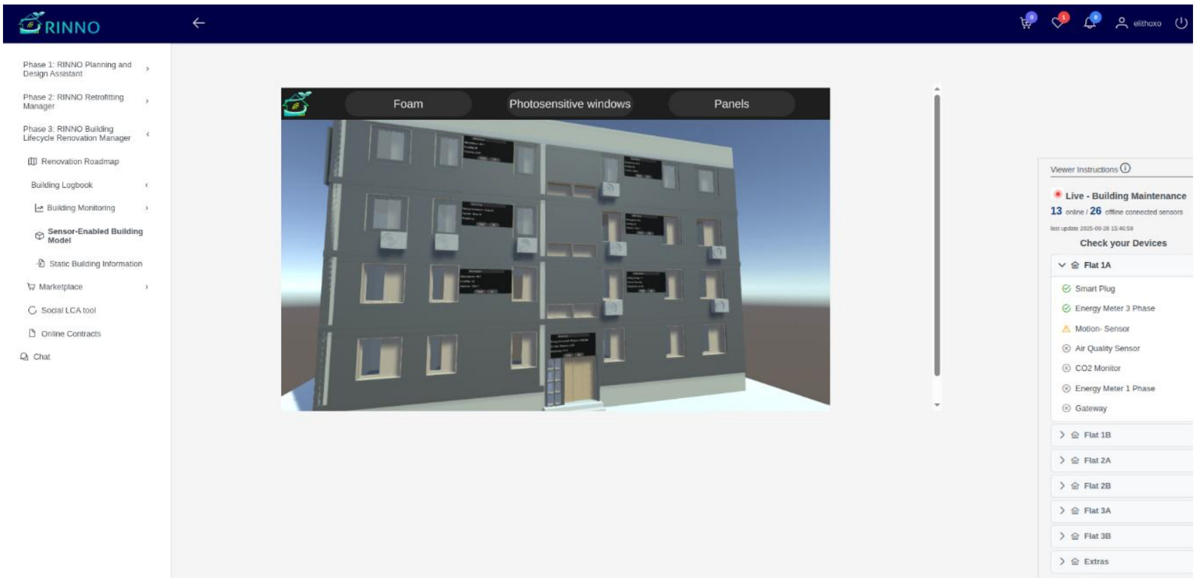

Figure 3-18: Sensor-Enabled Building Model integrating BIM information with real-time sensor data, providing a digital twin of the building and enabling visualization of device status and maintenance needs

Data Exchange

- The BIM model supplies static information such as building geometry, materials, floor layouts, and system designs.
- Sensors deliver dynamic data, including equipment status, energy consumption, temperature, humidity, and air quality, which overlay real-time performance information onto the BIM environment.
- Notifications are generated when anomalies are detected, such as sensor disconnections, equipment malfunctions, or deviations from expected values. These

notifications are then communicated through the Performance Dashboard and related monitoring tools.

Interconnection

- The integration of BIM with sensor data creates a comprehensive view that merges static design information with live operational insights. To ensure consistency, the platform uses the Pilot ID to correctly link the building's data to the right BIM model.
- When a malfunction is reported by a sensor (for example, HVAC failure or abnormal energy demand), the affected area is highlighted directly in the BIM model. This visual cue allows building operators to immediately locate the issue.
- The notifications system ensures that stakeholders, such as facility managers or maintenance teams, are alerted promptly and can act based on accurate spatial and operational data.

Practical Use

The system shows a 3D BIM view of the pilot building with sensor devices mapped onto different flats and areas (flats, hall, air quality measurement point, and main counter). Each sensor is listed with its device ID and current connection status. The interface also shows how many sensors are online or offline, ensuring transparency of system availability.

Therefore, the Sensor-Enabled Model functions as a **digital twin**, where BIM provides the static backbone, sensors provide dynamic updates, and notifications ensure timely responses. This integration enhances monitoring, fault detection, and building maintenance by visually linking real-world events to their location within the building model.

4. Marketplace Integration with the RINNO Renovation Repository

The Marketplace acts as a hub for technologies, materials, and solutions sourced from the RINNO Renovation Repository. It provides building owners, construction managers, and contractors with a curated selection of renovation technologies, organized into categories for easy navigation, such as "Envelope Retrofitting Solutions," "Energy Systems," "Retrofitting Process Improvement Techniques," and "Business Models." Products include insulation materials, smart thermostats, and energy system components, each displayed with pricing, images, and product details.

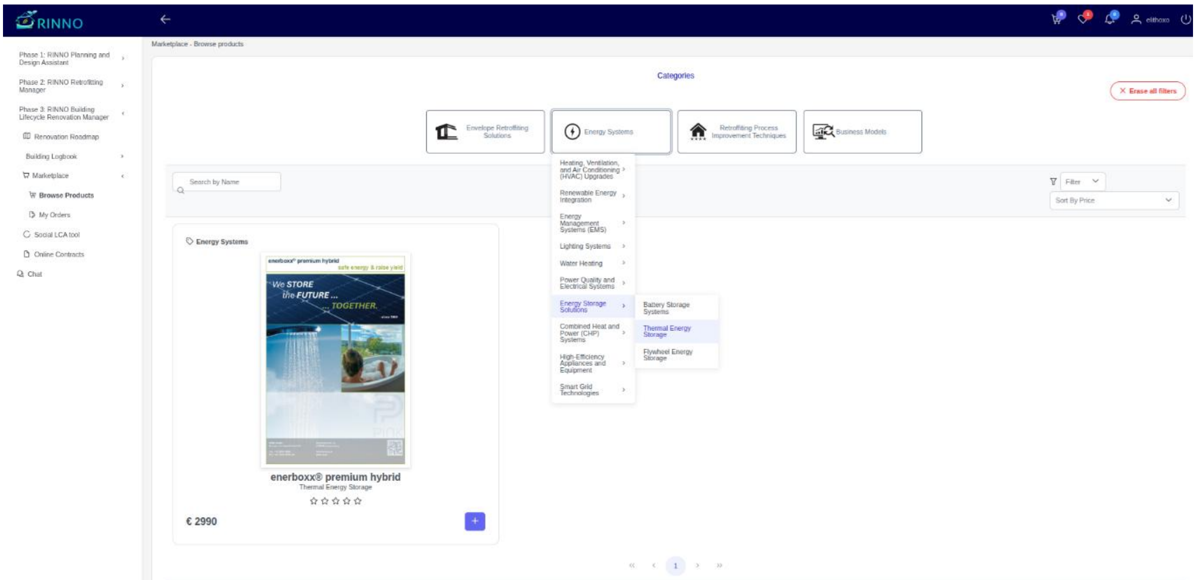

Figure 3-19: Marketplace interface allowing users to browse and filter renovation technologies and solutions by category, such as envelope retrofitting, energy systems, process improvement techniques, and business models

Data Exchange

- The Marketplace enhances the Renovation Repository by presenting up-to-date information on available technologies. Each entry includes technical specifications, performance data, certifications, and supplier details, ensuring that products meet industry standards and project requirements.

- Technology providers register to the RINNO Suite to insert and manage their products. Registration allows them to showcase innovative solutions, upload specifications, and ensure their products are visible to stakeholders planning renovation projects.

- User queries and browsing preferences are shared back to the Renovation Repository to refine recommendations and improve matchmaking between needs and technologies.

- Transactional data such as purchase orders and supplier engagements are stored in the Marketplace and shared with the Monitoring System. This enables tracking of installed technologies to evaluate whether they perform as expected after implementation.

Interconnection

- The Monitoring System communicates with the Marketplace to ensure that technologies used in real projects align with performance requirements.

- For example, if the Monitoring System identifies that a building is underperforming due to poor insulation, it can query the Marketplace for higher-efficiency insulation products sourced from the Renovation Repository. This creates a closed feedback loop between monitoring, planning, and procurement.

User Roles and Functions

- **Technology Provider (Seller):** Logs in with email and password, uploads and manages their own products, views products from other sellers, filters products by category, material, or characteristics, and sets pricing. They receive orders, manage them, and track engagement.

- **Construction Manager (Customer):** Logs in with their own credentials, browses all available products, views similar products by category, and uses filters to find solutions. They can add products to a wishlist, rate products, and view the aggregated ratings from all users. Customers add items to their cart (from one to many products) and proceed to checkout.

Checkout Process

At checkout, the customer enters billing information, shipping information, and payment details. The payment process is linked to PayPal through a developer account for demonstration purposes, using demo coins. Once the PayPal demo payment is completed, the order is automatically sent to the seller of the product or products.

In summary, the Marketplace connects technology providers with construction managers through a structured, category-based digital platform. It is directly integrated with the Renovation Repository and Monitoring System, ensuring that the solutions procured are not only technically relevant but also verifiable against real-world building performance.

5. Online Contracts for Job Facilitation and Agreement Execution

The Online Digital Contracts module is an essential part of the RINNO Renovation Workflow and Transaction Manager. It ensures that specific renovation phases cannot proceed without the proper legal and contractual agreements being signed between the involved stakeholders. At key transition points in the renovation workflow, the system automatically generates an online contract. For example, once the Planning and Design phase is complete, an online contract is created to formalize the start of the renovation phase.

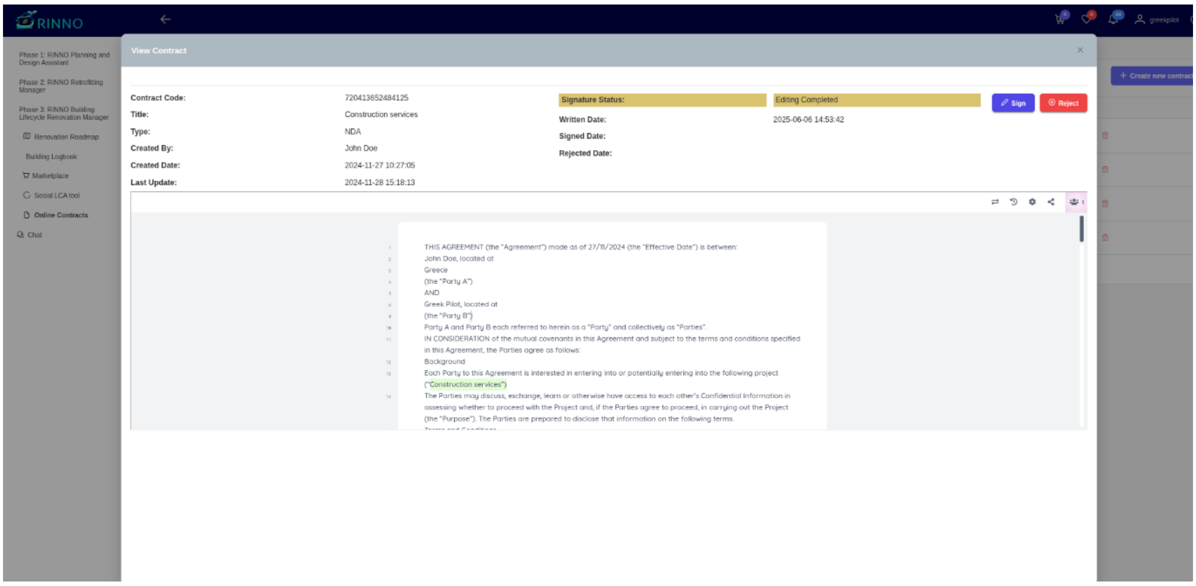

Figure 3-20: Online Contracts module enabling the creation, editing, signing, and management of digital agreements between renovation stakeholders, ensuring workflow continuity and accountability.

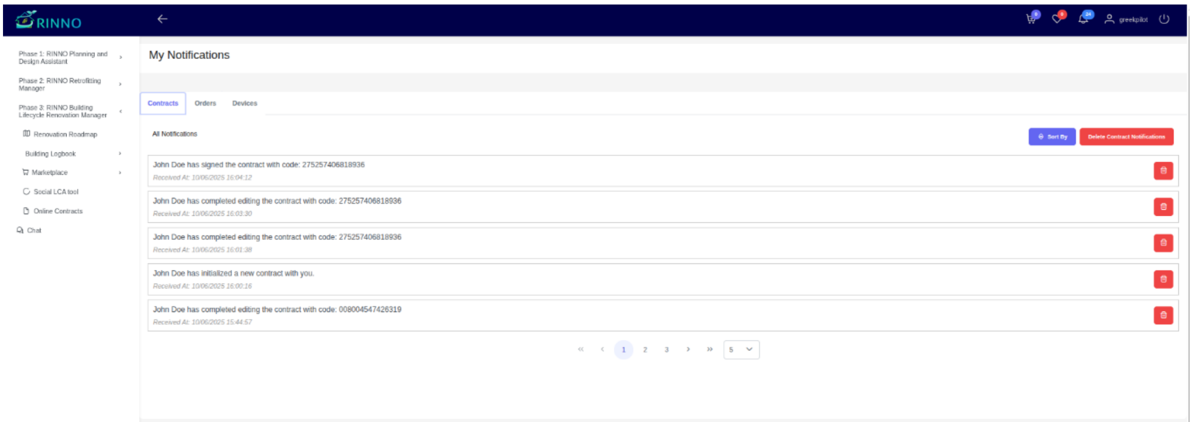

Figure 3-21: Notifications module providing real-time updates on contracts, orders, and device activities, ensuring stakeholders remain informed of key actions and workflow progress

These contracts include all relevant stakeholders, such as the building owner, construction manager, and any other project partners, ensuring mutual agreement before moving forward. Users can create new contracts manually or review those generated automatically by the system. Each contract includes details such as contract code, title, type (e.g., NDA, budget agreement, workflow contract), creator, and timestamps for creation and last update. The signature status is tracked (e.g., Editing, Editing Completed, Signed, Rejected). The contract cannot advance to execution until the required stakeholders have signed it.

Contracts can be viewed, edited, or deleted depending on user permissions. A visual indicator shows the contract's progress, and a button allows the creator to mark editing as complete once the contract is ready for signatures. If the contract is not signed, the renovation workflow halts at that stage, preventing the start of construction until legal agreements are in place. Contracts may occasionally display "Service Unavailable" if the server is under maintenance or overloaded, as shown in the screenshot, but they remain stored in the system.

All contracts are logged in the Online Contracts overview table, where users can filter, search by title, and track their status in real time. The Online Digital Contracts act as the binding element between workflow stages, stakeholders, and financial commitments. By digitizing this process, the platform ensures accountability, legal compliance, and transparency across renovation projects.

The Online Digital Contracts system ensures that renovation projects cannot move forward without proper authorization. It automates the creation, management, and signing of contracts, directly linking legal agreements to the renovation workflow stages and stakeholder responsibilities. For example, if the Monitoring System identifies that an HVAC system is underperforming, the following workflow occurs:

a) The Sensor-Enabled Model flags the affected unit within the BIM environment and notifies stakeholders.
b) The Marketplace is queried for replacement parts or upgraded solutions, leveraging the RINNO Renovation Repository.
c) The Online Contracts module facilitates hiring a contractor to replace or repair the system.

This interconnected approach ensures all tools work in harmony, delivering an optimized and data-driven renovation experience.

Testing and Validation

This section outlines the testing and validation activities performed to ensure the correct integration of the RINNO components and their readiness for operational use. Testing focused on verifying that individual modules function as expected, that data exchange across modules is seamless, and that end-user workflows are fully supported from planning to renovation execution.

- To validate the functional correctness of each component.
- To test data interoperability and interconnection between systems.
- To confirm that user roles (e.g., building owner, construction manager, technology provider) are able to perform their expected tasks.
- To ensure that acceptance criteria defined in the project requirements are met.

Renovation Roadmaps Validation

- **Test focus**: Verify the creation of baseline and multi-step renovation roadmaps; confirm that energy, cost, and CO_2 indicators update dynamically when new measures are added.
- **Validation activities**:
  - Input building data and generate two alternative renovation pathways.
  - Compare displayed indicators (primary energy, cost, emissions) against simulation outputs.
  - Validate aggregated totals (CAPEX, OPEX, savings) presented in roadmap summaries.
- **Acceptance criteria**: Roadmap visualizations accurately reflect input data and selected measures; comparison between pathways is available.

Building Monitoring System Validation

- **Test focus**: Assess Performance Dashboard and real-time Monitoring System.
- **Validation activities**:
  - Compare expected vs. actual energy demand as calculated from sensor inputs.
  - Validate time-series visualization of environmental variables (temperature, humidity, CO_2) across selected time ranges.
  - Trigger system alerts when actual values exceed thresholds.
- **Acceptance criteria**: Dashboard metrics are consistent with sensor data; graphs update in near real-time; alerts are delivered correctly.

Sensor-Enabled BIM Model Validation

- **Test focus**: Integration of static BIM data with dynamic sensor feeds.
- **Validation activities**:
  - Map devices in the BIM model to their real-world counterparts (e.g., HVAC, air quality sensors).
  - Simulate a sensor malfunction and confirm that the BIM model

highlights the affected area.

  - Validate notification delivery to relevant stakeholders.

- **Acceptance criteria**: The digital twin accurately represents real-time building status; malfunctions trigger notifications; Pilot ID ensures correct building model loading.

Marketplace Validation

- **Test focus**: Product registration, browsing, purchasing, and data exchange with the Renovation Repository and Monitoring System.
- **Validation activities**:
  - Register a product as a Technology Provider and validate product listing with specifications.
  - Browse and filter products as a Construction Manager; add to wishlist and cart.
  - Complete a test order using the integrated PayPal developer account and verify order notification to the seller.
  - Validate feedback loop between Monitoring System and Marketplace (e.g., recommending insulation products when higher efficiency is needed).

- **Acceptance criteria**: Marketplace supports end-to-end workflows for both providers and customers; transactions are logged; product data integrates with monitoring insights.

Online Digital Contracts Validation

- **Test focus**: Automated contract generation at workflow milestones, signing process, and blocking of further renovation steps until contract completion.
- **Validation activities**:
  - Complete Planning and Design phase and verify automatic generation of a renovation contract.
  - Simulate multi-stakeholder signing (building owner and construction manager).

   - Attempt to proceed without signing and confirm that the workflow is blocked.
   - Validate system response to different contract statuses (Editing, Signed, Rejected).

- **Acceptance criteria**: Contracts are automatically generated and tracked; renovations cannot proceed without signed agreements; stakeholders can view, edit, and sign as required.

Testing was extended to validate end-to-end workflows across modules:

- **Planning-to-Renovation Flow**: Building data entered in the Planning and Design Assistant produced renovation roadmaps. Once planning was completed, an Online Digital Contract was automatically generated. Renovation only proceeded after signatures were confirmed.

- **Monitoring-to-Marketplace Flow**: Deviations identified in the Performance Dashboard triggered recommendations in the Marketplace (e.g., replacement insulation). Purchased products were logged and validated against Monitoring System data for performance tracking.

- **BIM Notifications Flow**: When a malfunction was reported by a sensor, the BIM model highlighted the device location and sent a notification, which was also reflected in the Performance Dashboard.

User acceptance testing (UTAUT) was conducted with representative roles:

- **Technology providers** tested product registration and order management.

- **Construction managers** tested browsing, product selection, order placement, and contract signing.

- **Building owners** tested roadmap visualization, contract signing, and monitoring dashboards.

Feedback confirmed that the system is intuitive and supports renovation workflows effectively, although recommendations were made for interface improvements and response times under high sensor data loads.

The testing and validation activities confirmed that the RINNO components are successfully integrated, data flows between them are consistent, and workflows enforce necessary checks (e.g., digital contracts before renovation). Acceptance tests demonstrate that the system meets functional and interoperability requirements, providing a robust digital ecosystem for deep renovation projects.

3.1.4 Middleware Integration

Integration of monitoring sensors to the RINNO Suite - Access of data provided to other tools (e.g. VERIFY, s-LCA)

The integration of the middleware that connects monitoring sensors to the RINNO Suite is a critical component of the system's architecture. This middleware acts as a data aggregation and distribution hub, enabling the seamless exchange of sensor-derived data with various tools such as VERIFY and s-LCA, BIM viewer, Performance Dashboard etc. The integration employs a combination of MQTT servers for real-time data streaming and REST APIs for structured data access, ensuring flexibility, scalability, and compatibility with diverse use cases.

At its core, the middleware establishes a robust connection between the sensors deployed in monitoring systems and the RINNO Suite. Sensors installed in pilot sites continuously collect data such as temperature, humidity, energy consumption, and device operational status. This data is transmitted to the middleware using standardized IoT communication protocols, ensuring consistency and reliability. The middleware ingests this raw data and processes it to extract meaningful insights, applying transformations or aggregations as necessary to align the data with the requirements of the tools that consume it.

The MQTT server plays a pivotal role in enabling real-time data streaming. MQTT (Message Queuing Telemetry Transport) is a lightweight messaging protocol designed for low-bandwidth, high-latency networks. Sensors publish data streams to specific MQTT topics hosted by the middleware. These topics are categorized based on data type or device location, facilitating organized data flow. Tools like VERIFY and s-LCA subscribe to these topics, receiving real-time updates whenever new data is published. This mechanism ensures that tools requiring live monitoring or immediate feedback can operate with minimal latency.

In parallel, the middleware offers REST APIs to provide structured access to historical and aggregated data. REST (Representational State Transfer) APIs allow tools to query specific datasets stored within the middleware's database. For instance, VERIFY can use the REST API to retrieve historical performance metrics of a building system for analysis, while s-LCA might access aggregated data on energy usage patterns to conduct sustainability assessments. The Performance Dashboard also is directly linked to the Sensor-Enabled Model, which serves as the dynamic digital 3D representation of the building. The Sensor-Enabled Model can establish a virtual model of the building by integrating real-time environmental and energy data gathered from IoT-enabled devices attached to the building. Sensors monitor key parameters like temperature, humidity, energy consumption, CO_2 levels, and indoor air quality.

Data gathered is transmitted into the Performance Dashboard, where a series of processing and visualization for actionable insights is done. The dashboard gives two key performance metrics:

- Performance Baseline (Pre-renovation-): The energy and environmental conditions of a building before it was renovated against which improvements could be measured.
- Actual Performance: It shows post-renovation, real-time operational performance of the building, thus allowing for continuous monitoring and validation of renovation outcomes.

This baseline and actual performance comparison will allow stakeholders to understand how well renovation measures are performing, find deviations, and make data-driven decisions on further building performance optimization.

The API endpoints are designed to support complex queries, including filtering, sorting, and data aggregation, ensuring flexibility in data retrieval.

To facilitate this dual-mode integration, the middleware includes a data broker that manages the distribution of sensor data between MQTT topics and the API endpoints. The broker ensures that data published by sensors is simultaneously available for real-time streaming and archival storage, enabling both instantaneous and retrospective analysis. Furthermore, the middleware incorporates data normalization and formatting layers to standardize incoming data from diverse sensor types and protocols. This ensures that the data is interoperable and adheres to the schemas required by consuming tools.

The middleware also integrates authentication and authorization mechanisms to ensure security, access control, and data integrity across the system. Authentication is achieved by requiring users to provide valid credentials, such as a username and password. Once authenticated, the system identifies the user through a unique User ID and associates them with a specific renovation project or test environment using a Pilot ID.

The authorization process determines access rights based on the User ID and Pilot ID, ensuring that only authorized users can interact with specific data and functionalities. Role-based access control is applied, where users are assigned different levels of permissions depending on their responsibilities, restricting access to sensitive information while allowing necessary interactions. The middleware dynamically loads relevant renovation project data based on the Pilot ID and filters functionalities according to the user's access rights.

To maintain security throughout a session, authentication tokens are used to grant time-limited access, which is continuously verified to prevent unauthorized actions. By implementing these authentication and authorization mechanisms, the middleware ensures that only approved users can access renovation project data, interact with real-time performance metrics, and utilize system functionalities while maintaining strict security and compliance protocols.

Similarly, each tool accessing the MQTT server or REST APIs must authenticate using secure credentials. Access rights are configured based on roles and permissions again, ensuring that tools can only access data relevant to their function . For instance, VERIFY might have read access to performance metrics, while s-LCA could be restricted to sustainability-related datasets.

The integration within the RINNO Suite provides a unified interface for managing the middleware, monitoring active MQTT topics, and configuring REST API endpoints. This interface simplifies the process of connecting new tools or sensors, enabling the system to scale seamlessly as additional use cases emerge. For example, if a new sustainability tool needs access to energy consumption data, it can be integrated by subscribing to the appropriate MQTT topic or querying the corresponding API endpoint.

By leveraging both MQTT servers and REST APIs, the middleware ensures that the monitoring sensors' data is accessible in real-time for dynamic applications and available for in-depth analysis in static scenarios. This architecture bridges the gap between raw data collection and actionable insights, empowering tools like VERIFY and s-LCA to perform detailed evaluations and contribute to the overall objectives of the RINNO Suite.

3.2 Pre-pilot testing

The KRIPIS Smart House pre-pilot building was used to as a means to test and validate specific processes/tools before implementing them to the RINNO Suite. This enabled the project partners to practice in a controlled environment before and reduced the amount of effort for applying the same practices in practice. The most prominent activities that the KRIPIS house was used for were:

- 3D scanning of the building. A dedicated CERTH team carried out the 3D scanning of the building as a preparatory exercise before conducting the scanning of the Greek Demo building in Athens. This served various purposes: i) familiarizing the team with the process of the scanning, the equipment and the software used and ii) allowed them to refine the workflow and troubleshoot any potential issues prior to visiting the Moschato site. This experience was valuable to the team providing valuable insights and maximizing the efficiency of the process when conducting the scanning of the more complex and demanding Greek demo building
- Installation of monitoring sensors. The KRIPIS Smart House was also equipped with a range of monitoring sensors to test their usability and integration as a pre-pilot activity. Sensors measuring energy consumption, indoor temperature, humidity, CO_2 levels, and occupancy were deployed to evaluate data accuracy, communication protocols, and interoperability with the RINNO Monitoring System. This exercise allowed the partners to assess installation procedures, sensor calibration, and data collection workflows in a real environment before scaling up to the pilot buildings. The lessons learned at KRIPIS were instrumental in optimizing sensor placement strategies, ensuring reliable connectivity, and validating how sensor data could be visualized and analyzed within the Performance Dashboard and BIM-based digital twin.

Both the 3D scanning and the monitor sensor deployment at the KRIPIS Smart house provided valuable foundation for the project. They served as controlled preparatory activities that allowed the consortium to test tools and processes in a smaller-scale environment before moving to the more complex demo buildings. These pre-pilot exercises reduced risks, increased team familiarity with both hardware and software components, and ensured that integration into the RINNO Suite would be smoother and more efficient.

4 Lessons Learnt

The validation and integration activities across the RINNO Suite have highlighted several important lessons that can inform future development and deployment of digital renovation ecosystems.

- Input quality drives roadmap accuracy

During the Renovation Roadmaps validation, it became evident that while the system successfully generates alternative renovation pathways and updates indicators dynamically, the accuracy of outputs relies heavily on the quality and completeness of the input building data. This underlines the need for robust data validation at the input stage, as even small inconsistencies can lead to misleading energy or cost estimates. Furthermore, users expressed the importance of clear visual comparisons between pathways, showing that the value of the tool lies not only in accurate calculations but also in how transparently and intuitively the results are communicated.

- System responsiveness matters in monitoring

In the Building Monitoring System validation, the tests confirmed that real-time dashboards and alerts are effective in tracking performance. However, the exercise also highlighted the challenge of maintaining system responsiveness under high volumes of sensor data. Users noted slower response times when multiple variables were being monitored simultaneously, suggesting the need for optimization of data processing pipelines and more scalable backend infrastructures.

- Standardization is key for digital twins

The Sensor-Enabled BIM model validation reinforced the usefulness of digital twins in providing a live representation of building performance. The ability to visualize malfunctions directly within the 3D model was found to be particularly valuable for both engineers and building managers. However, integration testing revealed that mapping devices consistently across different pilot sites can be complex due to variations in sensor naming conventions and installation practices. Standardization of device metadata and deployment protocols was identified as a critical enabler for smooth scaling across diverse projects.

- Marketplace value comes from integration, not complexity

The Marketplace validation demonstrated that end-to-end workflows—from product registration to purchase—can function smoothly within a single ecosystem. A key lesson was that the value of the Marketplace increases significantly when it is linked to monitoring insights, such as recommending products in response to identified performance gaps. Nevertheless, users also emphasized that the Marketplace interface should remain as simple as possible, since construction managers are unlikely to engage deeply with overly complex browsing and filtering systems.

- Contracts must balance control with flexibility

Validation of the Online Digital Contracts showed the clear benefit of integrating automated contract generation into renovation workflows. Blocking renovation progress until contracts are signed provided a strong safeguard for accountability and compliance. At the same time, feedback indicated that stakeholders expect flexibility in contract editing and negotiation, pointing to a need for enhanced version control and collaborative features.

- Cross-module dependencies require strong safeguards

End-to-end testing across workflows, such as from planning to renovation, monitoring to marketplace, and BIM notifications to dashboards, confirmed that the modules are interoperable and that data flows are consistent. One key takeaway is that cross-module dependencies must be carefully monitored, since a weakness or delay in one tool (e.g., monitoring) can propagate into others (e.g., marketplace recommendations). Robust error-handling mechanisms and clear user notifications are therefore essential for maintaining trust in the system.

- Security and data standards are crucial

Regarding middleware integration, the dual use of MQTT for real-time streaming and REST APIs for structured access was validated as an effective architecture. The pilot deployments demonstrated that this hybrid approach balances the need for immediate updates with the ability to perform retrospective analysis. However, lessons were also learned about the importance of data normalization and role-based access control. Without standardized data formats and strict security protocols, interoperability with external tools like VERIFY and s-LCA could easily be compromised. Authentication and authorization proved crucial for protecting sensitive building data, and future iterations should continue to strengthen these mechanisms to align with evolving cybersecurity standards.

- iFrame is a useful tool for connecting different tools located in the cloud.

An iframe (inline frame) is a web development feature that allows external content to be embedded directly within a webpage. In the RINNO ecosystem, iframes provide significant value by enabling the integration of different modules—such as the Performance Dashboard, BIM model, Marketplace, or Monitoring System—into a single interface without requiring the user to leave the platform. This approach enhances usability, supports modularity, and ensures that updates to external tools are automatically reflected in the embedded view. As a result, iframes facilitate seamless interoperability across RINNO components and provide a consistent, unified user experience.

However, the use of iframes also comes with limitations. These include potential security risks (e.g., cross-site scripting or clickjacking if third-party content is not properly controlled), performance issues when embedding large or data-heavy applications, and restricted styling or interaction across iframe boundaries.

To mitigate these risks, RINNO adopts a set of best practices. It is embedding content only from trusted, secure sources. It is using HTTPS and sandboxing attributes to restrict iframe permissions. Additionally, it is optimizing performance by lazy loading or dynamically resizing iframe content. Also, it is providing fallback mechanisms so that the embedded services become temporarily unavailable. By applying these strategies, iframes can be leveraged safely and efficiently, ensuring that their benefits—seamless integration and modularity—are realized while minimizing associated risks.

- Integration of the IT tools should take place very early – almost simultaneously with the development of the tools so that they are designed with the integration in mind

It is crucial to have an integration strategy in place for the hosting platform at the same as time as the tools are developing in order to ensure compatibility and seamless data flow. When integration is considered during the development of various tools, it allows developers to align on architecture standards, APIs, authentication methods etc. which ultimately results in a simpler, more cohesive system with reduced maintenance needs. To do so, the integration activities of Task 6.1 should start at the same time as the tasks related to theα development of the tools.

Conversely, the integration activities in RINNO were considered approximately one year after the development of the individual IT tools. At that stage the tools were at an advanced development stage by the relevant partners and crucial parameters had already been decided (data structure, protocols etc.). As such, the integration strategy had to consider the different parameters of each tool which made the process more time and resource consuming. This was proven to be a complex task involving additional rework (adjustments made to the tools as described in Section 3) and customised solutions. In future projects, it is imperative to consider commence the integration activities and planning at the outset of the tools development for to ensure a more efficient and cohesive result.

- Everything with REST-API – not desktop based

Tools that were developed as a plug-in for Revit, meaning that users must have Revit installed and a license in order to use it. This requirement significantly limits access and testing opportunities by stakeholders. For future development, it would be beneficial to create a more flexible tool that is not dependent on Revit, making it accessible to a wider range of users.

Finally, across all components, user acceptance testing (UTAUT) highlighted the importance of system usability and performance in real operational contexts. While the functional requirements were largely met, users repeatedly emphasized the need for intuitive interfaces, reduced system response times, and better visualization of results. The testing also confirmed that active involvement of stakeholders, technology providers, construction managers, and building owners, is essential not only for validating system features but also for shaping the tools so that they genuinely support day-to-day renovation workflows.

5 Conclusions

This Deliverable presents the work conducted for the integration of the various RINNO tools in one platform, the RINNO Suite. The Platform is a holistic solution that aims at facilitating and improving all stages of renovation, namely the design, construction and use phases of the building. The individual tools were developed in earlier stages of the project as stand-alone tools and significant efforts were made to integrate them into one unified platform which enables:

- User friendly workflow
- Seamless information flow between the tools
- Central authorisation through a user-management system
- Role-based access to the individual components of the Suite
- Collaboration of different actors working on same project through defining a Pilot ID
- Communication of different users through a social collaboration platform
- Integration of static and dynamic data through BIM and sensors (digital twin functionality)
- Real-time monitoring and performance validation
- Automated digital contracts ensuring workflow continuity and compliance
- Marketplace access for renovation technologies and solutions
- Notifications and alerts for anomalies or required actions

After analysing all possible interactions between the tools and the different stages of renovation, the integration of the tools followed the general process: i) At first connections between the various tools of each stage were defined and implemented, ii) Next, the connections between the different renovation stages were defined and implemented iii) the tools were then hosted to the RINNO Suite with the use of iFrame technology, and iv) the tools were amended in order to connect to the central User Management System of the platform.

This process involved several different versions of the tools to be developed along with extensive integration testing and debugging. In addition, the KRIPIS pre-pilot building was used for validating some of the integration activities. Once integration was successfully completed a training workshop was organised specific to the tools of each WP in order to i) provide training to the members of the RINNO Consortium and external participants on the use of the tools and ii) to obtain feedback on the practicality, user friendliness and user acceptance of the RINNO Platform. At the time of writing this Deliverable the tools of WP3 and WP5 where successfully integrated to the RINNO Suite so the training was conducted for the tools of the RINNO Planning and Design Assistant and the Building Lifecycle Renovation Manager. The tools of WP4 presented some technical challenges; completion of the integration of the RINNO Retrofitting Manager tools and the relevant training (scheduled for August 2025) was subject to overcoming these challenges.

During this demanding process several challenges were faced. These provided some key lessons which will be proven useful to the project partners in future projects aiming to facilitate and boost the efficiency of the renovation sector. The integration represents a first result in bringing together different stakeholders, from building owners and construction managers to technology providers and designers, to work under the same suite of tools. The RINNO Suite demonstrates the feasibility of such integration, while also highlighting areas where further optimizations and refinements will be required to ensure smoother workflows, stronger interoperability, and wider adoption in practice. The RINNO Suite has already demonstrated that such integration works in practice. At the same time, it also revealed where further improvements are still needed to make workflows smoother, data exchange stronger, and adoption easier across the industry.

ABOUT RINNO

RINNO is a four-year EU-funded research project that aspires to deliver greener, bio-based, less energy- intensive from a life cycle perspective and easily applicable building renovation elements and energy systems that will reduce the time and cost required for deep energy renovation, while improving the building energy performance. Its ultimate goal is to develop, validate and demonstrate an operational interface with augmented intelligence and an occupant-centered approach that will streamline and facilitate the whole lifecycle of building renovation.

For more information, please visit **https://rinno-h2020.eu/**

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