InCUBE
sustainable building innovations

WP1 – D1.5

User and system requirements and InCUBE architecture (v1)

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HORIZON-CL5-2021-D4-01
EUROPEAN COMMISSION

European Climate, Infrastructure and Environment Executive Agency
Grant agreement no. 101069610

This project is funded by the European Union's 'Horizon Europe Research & Innovation programme' under grant agreement No 101069610. This publication reflects the authors' view only and the European Commission is not responsible for any use that may be made of the information it contains.

Project contractual details

Project title	An INClUsive toolBox for accElerating and smartening deep renovation
Project acronym	InCUBE
Grant agreement no.	101069610
Project duration	48 months (01/07/2022 – 30/06/2026)

Document details

Deliverable no.	1.5
Dissemination level	PU
Work package	WP1
Task	T1.5
Due date	M9 (31/03/2023)
Actual submission date	M15 (15/09/2023)
Lead beneficiary	KENT
Contributing beneficiary/ies	CERTH, RINA-C, TERA, EVOLVERE, CIRCE

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History of changes

Version	Date	Beneficiary	Changes
0.1	12/04/2023	KENT	Initial version
0.2	26/04/2023	KENT	Merge contributions from CERTH and CIRCE
0.3	10/05/2023	KENT	Updates based on comments
0.4	21/06/2023	KENT	Update after a meeting with CIRCE and CERTH
0.5	06/07/2023	KENT	Final version of the architecture diagram
0.6	17/07/2023	KENT	Final version for internal review
1.0	28/08/2023	KENT	Integration of changes following CERTH review

Executive Summary

This document reports the expected InCUBE architecture based on the initial project description and input from the project partners. It aims to give an overview of the various InCUBE components, describe their inputs and outputs, and keep track of their readiness levels.

This document will represent the reference document where the partners in the consortium can find a description of the interactions between components.

The document starts with the existing definitions of the project pilots. In section 2, each pilot has provided an initial perspective on the stakeholders involved and the necessary interactions with the digital platform of the InCUBE project. This provides some initial requirements for the needs and purposes of the digital platform.

A first definition of the system requirements has then been built, presented in section 3. This is also preliminary work, but it already provides a range of expectations for the necessary capabilities of the digital platform.

The document also provides a complete perspective on the project assets, with their expected inputs and outputs. The interactions between the components have been described more precisely, and the underlying communication architecture has been drawn. This work has been critical to building the initial architecture of the project (presented at the end of section 4). This architecture will serve as a key reference point for the integration work in WP3. Finally, the report also presents a perspective on the components' technology, integration, and system readiness. This will form a baseline to track the progress of the integration work between components.

This deliverable will be followed by the implementation of components at a low readiness level and the integration of more mature ones. This document will be updated in two future revisions at different steps of the InCUBE project.

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List of Acronyms and Abbreviations

Term	Description
AB	Area Boundary
ACS	Anti-Collision System
AI	Artificial Intelligence
API	Application Programming Interface
AR	Augmented Reality
BIM	Building Information Modelling
CIM	Common Information Model
CSV	Comma-separated Values
DB	Database
DBL	Digital Building Logbook
DT	Digital Twin
EMS	Energy Management System
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
HVAC	Heating, Ventilation, and Air Conditioning
IFC	International Foundation Class
IoT	Internet of Things
IPD	Integrated Project Delivery
IRL	Integration Readiness Level
JSO	Job Scheduling Optimizer
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LPS	Last Planner System
MQTT	Message Queuing Telemetry Transport
PDF	Portable Document Format
PPE	Personal Protective Equipment
PV	Photovoltaic
RD	Resilience Dashboard
RES	Renewable Energy Sources
REST	REpresentational State Transfer
SAREF	Smart Applications REFerence (ontology)
SRI	Smart Readiness Indicator

SRL	System Readiness Level
TLS	Terrestrial Laser Scanning
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality
WebRTC	Web Real-Time Communication
WP	Work Package
XML	Extensible Markup Language

1 Introduction

1.1 Aim of the deliverable

This deliverable aims to provide a blueprint architecture for the overall InCUBE framework. It defines guidelines for seamless integration of the various technical components that will be implemented for future deliverables.

1.2 Dependencies with other tasks

This deliverable relies on the outcomes of task T1.3 - Pilot Sites Surveys & Definition of Use Case Scenarios (and the corresponding deliverable D1.3) to extract user and system requirements for all three demo sites.

Moreover, T3.1- Interoperability Framework for building systems, products, and operations, will be based on the architecture defined in this deliverable D1.5, in order to specify common APIs and data models to ensure the efficient data exchange among devices, data platforms, applications, services and operations.

The survey and list of project assets is also related to the work conducted in task 10.2 on innovation management and on Task 9.4 as part of the exploitation methodology. Indeed, the follow-up of the Integration Readiness level (presented in section 5) will serve as a foundation for analysing the exploitation readiness of the project platform in WP9.

1.3 Structure of the deliverable

Section 2 will describe the software-related use cases for each demo site, based on the answers of stakeholders. Section 3 will describe the user and system requirements, based on the use cases and on the description of each InCUBE component. Section 4 defines the overall architecture of the InCUBE framework. Section 5 will define the System Readiness Level (SRL) and Integration Readiness Level (IRL) to use to quantify and monitor the maturity of the different components.

The appendices contain the templates sent to the consortium partners to get a better understanding of their needs and proposals.

1.4 Methodology

This document is a compilation of the information about InCUBE components as described in early-stage documents, like the Grant Agreement, and in deliverables of other tasks. Based on this existing foundation, component owners were asked to provide additional component information. A survey was conducted using the template presented in annexes 7.1. Annex 7.2 has been prepared to request more precise use cases from the partners if necessary.

These descriptions were used to produce the architecture perspective of the components. This was done through the set-up of interaction matrixes. This initial view was then refined into architecture diagrams.

A final round of validation was then conducted to validate the components interactions descriptions that were used to prepare the architecture diagrams from section 4.3.

In parallel, the Integration and System readiness methodology (presented in section 5) was introduced to evaluate the initial readiness state of the project. This used the interaction matrixes to produce an initial perspective of the project platform system readiness. This initial technology and interaction readiness evaluation was validated with the owners of each component.

Finally, it is to be noted that the deliverable has also been written keeping in mind it will have to be updated during the project as it requires inputs from parallel tasks.

2 Use Cases

This chapter presents several use cases of the InCUBE platform according to the scenarios gathered from consortium partners. Inputs were retrieved using the form in section 7.1.

2.1 Trento (Italy) Demo Site

This section presents the different stakeholders of the Trento demo site and some of their use cases.

2.1.1 Use case description

The renovation occurs on the “Centro Servizi Santa Chiara” historical building in Trento. The building is located at the south-east corner of the historic centre and was built originally to be a monastery around 1235. Over the years the building faced different periods of wars, becoming a civil hospital. It was also involved in several renovations since the last intended use as a university. The building was renovated and used as a university for around 15 years. The building was progressively abandoned 5 years ago when a new university was created. The actual state of the building was for the most part abandoned. Just a small portion of the building is used as offices of the group “Centro Servizi Santa Chiara” and “Trentino Film Festival”. Over the years, it has been added to the historical building also a gym called “Palablocchi” and an auditorium theatre. All these buildings are properties of the Municipality of Trento.

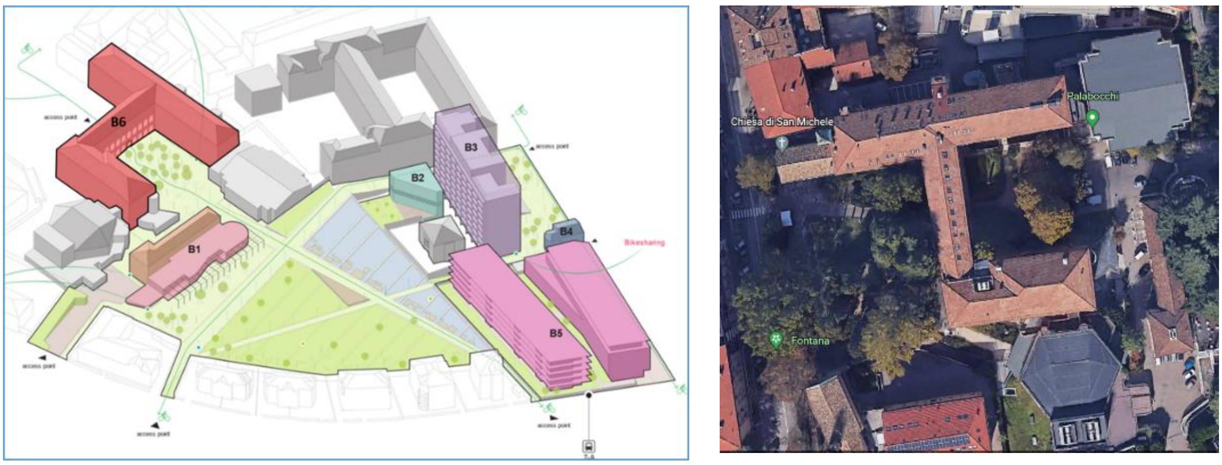


Figure 1 - Trento building

2.1.2 Stakeholders Definition

Stakeholder	Description	Expected rights of interaction
Demo Leader	Manages the demo site.	Read-only access to everything. Write access to documents.
Renovation Manager	Companies working of the renovation of a building	Read-only access to building and common-parts related BIM. Addition-only access to renovation workflow documents.
Ministry of Cultural Heritage	Authorizes/monitors work on historic buildings in Italy (Superintendency of Archaeology, Fine Arts and Landscape)	Read-only access to reports and BIM.
Municipality of Trento	Owns the building	Read-only access to everything. Write access to documents.

Table 1 - Italian Demo Stakeholders

2.2 Zaragoza (Spain) Demo Site

This section presents the different stakeholders of the Zaragoza demo site and some of their use cases.

2.2.1 Use case description

Zaragoza's demo site is a residential building included in Balsas de Ebro District, a neighbourhood developed between 1950 and 1970. Most part of the buildings that belong to this district have similar characteristics in relation to the typology, orientation, constructive systems, and configuration. Thus, high replicability potential can be expected. In addition, the neighbourhood of Balsas de Ebro Viejo belongs to an Urban Complex of Interest and has specific regulation regarding buildings' conservation and allowed refurbishment interventions. The main features of the buildings in the district are poor insulation, significant thermal bridges, and the lack of elevators. It is estimated that almost 100% of the building is occupied permanently.

The Pilot is a 5-storey building (has ground floor and four more levels) and is divided into four staircases with 10 dwellings each. In total, 40 dwellings conform the building. The main façades have East-West orientation and the shortest façades without windows have north-south orientation. Also, northern façade is partly connected to the following building.

Figure 2 - Zaragoza Building

2.2.2 Stakeholders Definition

Stakeholder	Description	Expected rights of interaction
Demo Leader	Manages the demo site.	Read-only access to everything. Write access to documents.
Renovation Manager	Companies working of the renovation of a building	Read-only access to building and common-parts related BIM. Addition-only access to renovation workflow documents.
Community of Owners (x4)	Legal community of dwelling owners, one per staircase Represents the owners.	Read-only access to building and common-parts related information. Write access to building documents.
Dwelling Owner	Owner of one or multiple dwellings. Might not be the occupant of the dwellings it owns. It is part of the Community of Owners.	Read-only access to dwelling details, except occupant privacy-related ones. Can define policies on the use of actuators.
Dwelling Occupant	Occupant of one or multiple dwellings. Might not be the owner of the dwellings it uses.	Read-only access to dwelling details. Read/Write access to actuators.

Table 2 - Spanish Demo Stakeholders

2.3 Groningen (Netherlands) Demo Site

This section presents the different stakeholders of the Groningen demo site and some of their use cases.

2.3.1 Use case description

The renovation occurs on a residential building for students.

The Dutch demo consists of an 11-floor building with an overall surface of around 9800 sqm. The Heemskerckflat was specifically designed for students. In the building students have their own room, connected to a common hallway. They share facilities as bathrooms, kitchens, and dining areas. This way of living is outdated and there is a surplus in shared spaces. In the new design the rooms will be extended. Each room will have their own bathroom. On each floor the rooms will be divided in four groups of seven rooms – communities - with a shared kitchen for each community. Public facilities for all the residents in the building, such as a library, living room and washing machines will be located on the ground floor. The upper level of the building will be expanded and improved as current fire safety measures do not meet the current requirements. Since this is a residential building, it is expected to be used continuously throughout all the year and the day. The maximum occupancy is around 265 occupants.

Figure 3 - Groningen building

2.3.2 Stakeholders Definition

Stakeholder	Description	Expected rights of interaction
Demo Leader	Manages the demo site.	Read-only access to everything. Write access to documents.
Renovation Manager	Companies working of the renovation of a building	Read-only access to building and common-parts related BIM.

Stakeholder	Description	Expected rights of interaction
		Addition-only access to renovation workflow documents.
Room Occupant	Occupant of a room	Read-only access to dwelling details. Read/Write access to actuators.

Table 3 - Dutch Demo Stakeholders

2.4 Summary of the different Use Cases

This section will summarize the different stakeholders and requirements found in the description of the various demo sites use cases. Those use cases were not defined in the first version of this deliverable. They should be added in the next review, based on the results of work package 7.
The requirements defined in this section will then be used to describe the user requirements.

2.4.1 Stakeholders

At the first iteration of this document, we see that the potential stakeholders can be grouped into 6 categories:

1. Demonstration leader / project reporter
2. Renovation manager
3. Renovation worker
4. Building owner (or community of owners)
5. Building management entity (governmental, municipal, or owner)
6. Building occupant (living or working in the building)

2.4.2 Requirements

No detailed requirements for the InCUBE digital platform were defined based on the initial version of this document. They will be defined in the upcoming month as a result of the joint work of WP1 and WP7 and will be presented in next iterations of this deliverable.

3 InCUBE Suite Requirements

This section presents the requirements extracted from section 2 and feedback from consortium partners.

3.1 System requirements

InCUBE Suite high-level system requirements, formulated based on main project objectives and foreseen functionalities, are summarized in table below.

Ref	Requirement description
R1	Platform must centralize storage of different types of data related to buildings and renovation processes and products (in the form of a data lake).
R2	Platform must support storage and distribution of both static and dynamic real-time data.
R3	Components must be loosely coupled. Integration must ensure the use of well-specified interactions among the components. Also, data exchange should be possible through the centralized data lake.
R4	Platform must support access control, authentication, and authorization mechanisms, to allow access to building information across the life cycle for different relevant stakeholders (such as owners, facility managers, contractors, public authorities).
R5	Middleware implementation must be able to collect heterogeneous data from different types of equipment and sensors and push the data to the data lake for storage.
R6	IoT data must be semantically enriched (e.g., using well-known ontologies and formats) to ensure cross-domain interoperability.
R7	Platform must have a dedicated engine for the creation of digital twins: BIM-based digital twins of buildings, systems, and products.
R8	Platform must provide user-friendly User Interfaces and dashboard views to be used by people with no technical knowledge (such as dwelling owners, public authorities, etc.).
R9	Platform User Interfaces should ensure accessibility (e.g., following Web Content Accessibility Guidelines)
R10	Platform must allow third parties to enrich the InCUBE Renovation marketplace with additional content, such as innovative technologies, processes, and good practices.
R11	Platform must make available business models, training material, and other services for users, following the gender mainstreaming principles (as a web application).
R12	Platform must itself be efficient regarding energy consumption

3.2 Key Performance Indicators

Here is the list of indicators we will use to follow the progress of the project integration.

Ref	Description	Category
KPI1	Total cost of the platform	Development status
KPI2	System Readiness Level	Development status
KPI3	CO2 emissions savings	Environmental impact
KPI4	Energy consumption savings	Energy impact

4 InCUBE Framework Architecture

This section describes the overall architecture of the InCUBE framework.

4.1 Overall description

The architecture we define in this chapter is a detailed review of the initial framework description shown in Figure 4. This architecture was considering direct links between the various components of the InCUBE framework. It was also designed to store part of the data in the Logbook. The external users were limited to access only the Logbook.

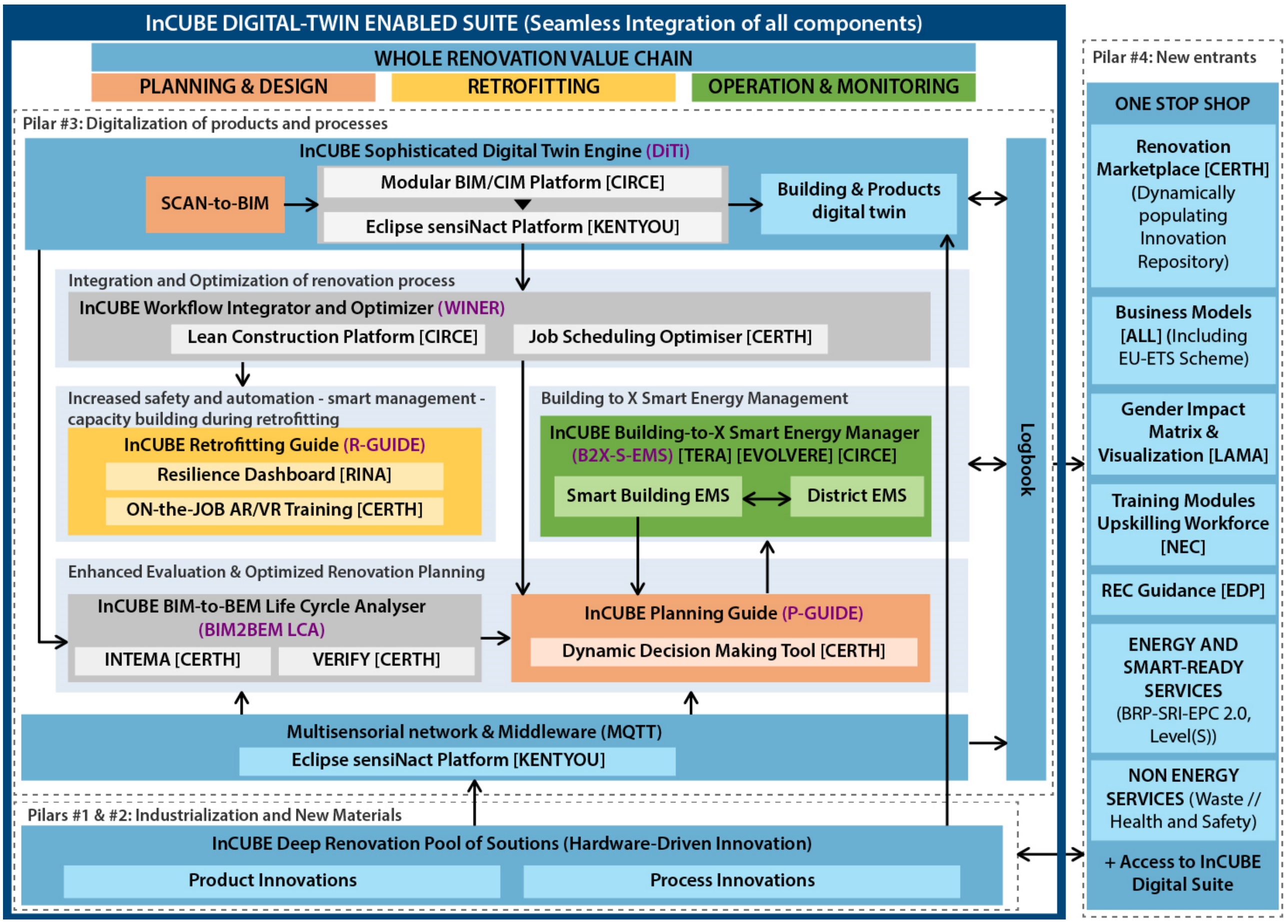


Figure 4 - Initial architecture proposal

The proposal of the current document is to increase the central place of the Digital Building Logbook and to redefine the interactions between the new entrants and some InCUBE components. The objective is for the Digital Building Logbook to keep track of all the events that occur in the building and of all computation results that they trigger. This will allow a better understanding of the behaviour of both the building and the InCUBE framework. The real-time representation of the building will be stored and provided by the Eclipse SensiNact component from the Digital Twin component group. The events it receives will be sent to the Digital Building Logbook. Finally, the BIM/CIM platform will be the component where to find the descriptions of the buildings and of individual products. It is recommended for InCUBE components to interact with the Digital Building Logbook, Eclipse SensiNact or the BIM/CIM platform to obtain the data they require. It is acceptable that components from the same component group exchange data directly with each other.

4.2 Description of InCUBE Components

This section describes the various components of the InCUBE framework and their relations. This is a software-oriented view of the framework, which means that physical objects and operations are presented through their software interactions or specification document format. This section will first present the common components and the expected interactions with components that are provided by on-site-specific implementations. It will continue by listing the other components according to their relationship with the common components.

4.2.1 Software components common to all demo sites

This section describes the InCUBE components that will be deployed on all demonstration sites. They can be considered as a large part of the InCUBE core components. The final part of this section will discuss the expected concepts to fulfil the purpose of the InCUBE framework.
The Energy Management Systems are not defined here as there will be different implementations across demonstration sites.

4.2.1.1 Digital Building Logbook: InCUBE Data Lake

Owner	Component group
CERTH	Core component

The Digital Building Logbook (DBL) is a component with a key role in the InCUBE system architecture. This is because it is the repository of InCUBE, responsible for storing and providing access to data. DBL has a form of a Data Lake. A Data Lake is a centralized repository designed to store, process, and secure large amounts of data (structured, semi-structured, and unstructured data)[1]. For example, a Data Lake can include structured data from relational databases (rows and columns), semi-structured data (e.g., CSV, XML, JSON), unstructured (e.g., pdf documents) and binary data (e.g., images, audio, video).
DBL has been designed to host both static and dynamic data that describe various entities such as buildings, hardware products, devices, and sensors, and other. In particular, DBL will be storing and

[1] https://cloud.google.com/learn/what-is-a-data-lake

providing access to historical dynamic data coming from the multi-sensorial network as well as static data about buildings and building systems. Furthermore, it will be responsible for storing results generated by various InCUBE components (digital tools), making it a live, dynamic logbook that documents building design, operation, and performance through time. As a result, DBL will be able to support the delivery of InCUBE data-driven innovations and services.

The DBL must be able to support requests for data insertion and data retrieval, as well as requests for updating and deleting existing data. Another important objective is to ensure secure access to the data. This will be possible mainly through the use of secure communication protocols that encrypt traffic and the use of a token-based authentication mechanism that will be implemented by the DBL. Lastly, DBL will provide a data catalogue service (indexing of data), in order to facilitate the discovery of stored data by the data consumer components.
The complete list of detailed functional and non-functional requirements, as well as the specifications of the DBL component will be described in deliverable D3.6 (M20).

Input

The components that use the Logbook to store documents, reports, or other output data will access it using a HTTP REST interface. In addition, the components notifying the Logbook to store new events, such as measurements from sensors, will be able to use either the provided HTTP REST interface or alternatively the Message Queuing Telemetry Transport (MQTT) protocol.
A list of components that will store data to the Digital Building Logbook is provided in the table below:

Input origin	Access description	Input Format
Eclipse SensiNact Platform	Propagates events from IoT sensors and smart devices	JSON and/or XML
Report generators	Store (push) generated documents by InCUBE components	various file extensions (e.g., PDF)
Other data generators	Store (push) generated output data by InCUBE components	JSON and/or XML

Read access to other components

This component receives data but does not actively look for it. It can link to other data, like a BIM model in the Modular BIM/CIM platform, but it will not access it directly.

Access by other components

A list of components that retrieve data from the Digital Building Logbook is provided in the table below:

Client component	Access description	Access protocol
P-GUIDE	Retrieves properties of products, Checks history of event	HTTP REST
Eclipse SensiNact Platform	Update on live events	HTTP REST / MQTT
VERIFY	Retrieves performance data and data from EMS sensors	HTTP REST
INTEMA	Retrieves sensors/performance information	HTTP REST
AR/VR Training Suite	Retrieves asset information, processes definitions, training material of products	HTTP REST
Renovation Marketplace	Retrieves information of assets/products	HTTP REST
Future client components	Client-specific needs	HTTP REST

4.2.1.2 Modular BIM/CIM Platform

Owner	Component group
CIRCE	InCUBE Sophisticated Digital Twin Engine (DiTi)

This solution is a modular (able to swap BIM object categories) and interoperable web-based repository of BIM objects (incl. conventional and novel building solutions) – reducing modelling time by at least 20% in comparison with conventional modelling process without the use of a standardized library.

Input

This component will receive BIM files associated with the 3D representation of the buildings. The point clouds resulting from 3D scanning and the eventual 3D models can be either included or associated to the BIM files. The input formats will be different depending on the providers.

Input origin	Access description	Input format
Existing BIM documents	One-time storage of existing content	Revit, IFC
3D Scanning components	Store point cloud and/or 3D models of the building	OBJ, PLY, RCP, BLK
BIM of Building designs	Store 3D models of the building	Revit, IFC
BIM objects repository	Store available BIM objects (families)	Revit, IFC

Read access to components

This component does not get data from other components as it is expected to be updated directly and manually.

Access by other components

The information and 3D models must be easily accessible in formats that enhance interoperability. The platform is accessible through a web interface. It will be necessary for it to be usable programmatically by other components using a REST interface over HTTP(S) and returning files in an interoperable format *e.g.*, IFC for BIM details and PLY for 3D models.

Here is the list of components retrieving data from this component:

Client component	Access description	Access protocol
AR/VR Training Suite	3D models of buildings and items	HTTP
Renovation Marketplace	Description of BIM items	HTTP
INTEMA	Building BIM (with 3D model)	HTTP
Lean Construction Platform	3D models of the building	HTTP
P-GUIDE	Retrieve properties of products, characteristics of the buildings	HTTP
Eclipse SensiNact Platform	Access BIM models	HTTP
Renovation Marketplace	BIM assets list	HTTP
Smart Building EMS (S-BEMS)	Building information and 3D structure	HTTP
Energy Cloud EMS	Building information and 3D structure	HTTP

4.2.1.3 Eclipse SensiNact Platform

Owner	Component group
KENT	InCUBE Sophisticated Digital Twin Engine (DiTi)

Eclipse SensiNact is a modular, open-source edge to cloud, digital twin platform that was created to rapidly integrate heterogeneous infrastructures, thus being compatible with a variety of smart connected devices and environments at the building and district level. It collects, via APIs, and processes data from heterogeneous sources; applies AI for decision making, carries out predictive analysis; and redistributes actionable information.

The Eclipse SensiNact platform keeps track of the status of various sensors using different protocols. The platform ensures that the events it propagates are associated to a time, a value and represent the sender using a mode, provider, service, resource addressing.

Input

Input origin	Access description	Input format
Sensors	Subscribe/Poll updates from various kinds of sensors	HTTP poll, MQTT, …

Read access to components

The Eclipse SensiNact platform will access the Digital Building Logbook and the Modular BIM/CIM platform to obtain the history of the building and its BIM description. It will not proactively retrieve data from other components.

Target component	Access description	Input format
Digital Building Logbook	Access history of events	HTTP
Modular BIM/CIM Platform	Access BIM models	HTTP

Access by other components

InCUBE software components are expected to push the events they receive to the Eclipse SensiNact platform, which will update its digital twin model and push those events to the Digital Building Logbook. It is preferred that components that need to subscribe to live events should subscribe to the Eclipse SensiNact platform instead of listening to the sensors directly. This will increase the possibilities of sensor abstraction and the reusability of the overall platform.

Client component	Access description	Access protocol
Smart Building EMS (S-BEMS)	Push sensors events	HTTP REST / MQTT
Resilience Dashboard	Push safety events	HTTP REST / MQTT
Job Scheduler Optimizer	Real time sensor data	HTTP REST / MQTT
Components requiring real-time events	Subscription to real-time events	HTTP REST / MQTT

Write access to components

The Eclipse SensiNact platform will propagate the events it receives to the Digital Building Logbook. It can also push BIM updates to the logbook.

Target component	Access description	Access protocol
Digital Building Logbook	Propagates events from IoT sensors and smart devices	MQTT

Target component	Access description	Access protocol
Digital Building Logbook	Pushes the description of buildings read from Modular BIM/CIM platform	HTTP

4.2.1.4 INTEMA

Owner	Component group
CERTH	InCUBE BIM-to-BEM Life Cycle Analyzer (BIM2BEM LCA)

INTEMA.building is a submodule of the general INTEMA Suite of tools, which uses as basis white-box models of physical energy-related assets, further strengthened when historical or real-time data are available, with black-box developed models; rendering a grey-box model in the field of energy. Using this open-access grey-box modelling approach, simulations of various energy systems can be performed (district heating networks, electrical grids, combustion power systems etc.). In addition, custom-made tools are being developed in various programming languages (e.g., Python) to support specific research needs. INTEMA platform is offered as a web application. The user determines the inputs through an easy-to-use GUI (building envelope components, building systems, RES systems, location, and weather data etc.), whilst the appropriate structure of the Modelica model and the relevant libraries required are automatically generated at the back end. This automation results in significant time savings in simulation and enables the use of the software by sustainability experts/ engineers without requiring specialised programming skills.

Input

Input origin	Access description	Input Format
Modular BIM/CIM platform	Description of a building (BIM)	IFC (HTTP)

Read access to components

Target component	Access description	Access protocol
VERIFY	Simulation results	HTTP
Digital Building Logbook	Sensors/Performance information from S-BEMS	HTTP
Modular BIM/CIM platform	Retrieve the description of a building (BIM)	HTTP

Access by other components

Client component	Access description	Access protocol
VERIFY	Requests INTEMA to check for status updates	HTTP

Write access to components

Target component	Access description	Access protocol
VERIFY	Building parameters and renovation scenarios definition	HTTP
Digital Building Logbook	Store results and reports	HTTP

4.2.1.5 VERIFY

Owner	Component group
CERTH	InCUBE BIM-to-BEM Life Cycle Analyzer (BIM2BEM LCA)

VERIFY is an online web-based platform, performing environmental and cost oriented analysis and computations. A PostgreSQL database is responsible for keeping all the important information secure and updated. VERIFY main advantages, over similar available commercial tools, lie on the web server installation, the variety of computations it can perform and the use of open-source programming libraries. Communication with remote sensors is achieved through MQTT messaging transport protocol.

Input

Input origin	Access description	Input Format
File upload	Manual provision of content	CSV
Sensors	Supports MQTT updates from sensors	JSON (SAREF ontology)

Read access to components

Target component	Access description	Access protocol
INTEMA	Requests INTEMA to check for status updates	HTTP
Digital Building Logbook	Access to EMS sensors/performance data	HTTP

Access by other components

Client component	Access description	Access protocol
INTEMA	Push building parameters and renovation scenarios definition	HTTP
P-GUIDE	Retrieve energy performance information	HTTP

Write access to components

Target component	Access description	Access protocol
Digital Building Logbook	Store LCC/LCA reports	HTTP
P-GUIDE (Dynamic Decision-Making Tool)	Environmental and cost indicators values	HTTP
WINER (Job Scheduler Optimizer and/or Lean Construction Platform)	Environmental and cost indicators values	HTTP

4.2.1.6 InCUBE Planning Guide (P-GUIDE)

Owner	Component group
CERTH	InCUBE Planning Guide (P-GUIDE)

The InCUBE Planning Guide (P-GUIDE) is a tool able to evaluate different renovation scenarios in respect to various pre-defined KPIs, in order to propose to the user the optimal renovation scenario. The KPIs to be considered for proposing the best renovation scenario are related to cost, retrofitting time, SRI index, disturbance level, environmental impact, and energy impact. The incorporated decision support algorithm is responsible for assessing multiple solutions and calculating the total scores based on the priority weight of each KPI. A web-based user interface will also allow the user to enter his/her preferences regarding the considered KPIs and the priority of each KPI.

P-GUIDE will make use of information from modelling and evaluation tools such as VERIFY, INTEMA, and Job Scheduling Optimiser, as well as the characteristics of customised models for InCUBE's new products that will be available through the Digital Building Logbook. Thus, the latest available information will be utilised each time resulting in re-adaptations of the optimum renovation scenario.

The back-end module of the P-GUIDE will implement and provide a complete HTTP web API for configuration, input data setup and output result, allowing easy integration with other components (e.g., WINER). The key advantage over similar solutions is that it can be easily customized to communicate with BIM/CIM models, LCA-LCC tools and DTs.

The result will be a user-friendly tool that owners or renovation companies can use for planning deep renovation. A detailed description of the P-GUIDE tool will be provided in deliverables D4.2 on M20 (first version) and D4.6 on M41 (final version).

Input

Input origin	Access description	Input Format
Modular BIM/CIM Platform	Retrieve characteristics of the buildings, properties of products.	IFC (HTTP)
INTEMA	Energy performance information provider	JSON (HTTP REST)
VERIFY	Environmental and cost information provider	JSON (HTTP REST)
Job Scheduling Optimizer	Receive information about retrofitting time and optimal sequence of interventions	JSON (HTTP REST)

Read access to components

Target component	Access description	Access protocol
Digital Building Logbook	Retrieve properties of products, and dynamic information (current situation). Store and re-use output results. Retrieve outputs of modelling and evaluation tools of InCUBE (INTEMA)	HTTP REST
Modular BIM/CIM Platform	Retrieve properties of products, characteristics of the buildings	HTTP / IFC
Eclipse SensiNact Platform (DiTi)	Sensory data provider	JSON (HTTP REST)
VERIFY	Environmental and cost indicators values	HTTP REST / JSON
Job Scheduling Optimizer	Optimal sequence of interventions and retrofitting time	HTTP REST / JSON

Access by other components

Client component	Access description	Access protocol
Digital Building Logbook	Store outputs (in JSON format)	HTTP REST
Job Scheduling Optimizer	Send the optimal renovation scenario	HTTP REST
Lean Construction Platform	TBD	TBD

4.2.1.7 Resilience Dashboard

Owner	Component group
RINA-C	InCUBE Retrofitting Guide (R-GUIDE)

The Resilience Dashboard (RD) is a single management platform that enables the communication and orchestrated use of different technological tools that lead to a "Resilient Construction Site" (RCS). RD integrates several tools (on-site process innovations) that respond to the needs of the site, organized in 3 sections: a) Safety at Work, b) Environmental and Waste Management and c) Vehicle and Equipment Management. The implementation of RCS can lead to: increased process efficiency (20%), decrease in accidents (20%), decrease in litigation costs or site steps (10%).

Input

Input origin	Access description	Input Format
Lean Construction Platform	Renovation status	
Modular BIM/CIM Platform	Buildings description	IFC

Read access to components

The access to the Modular BIM/CIM platform to update the description of buildings is a possible improvement.

Target component	Access description	Access protocol
Lean Construction Platform	Renovation status	TBD
Modular BIM/CIM Platform	Possible updates of buildings description	HTTP / IFC

Access by other components

Client component	Access description	Access protocol
AR/VR Training Suite	Access to reports and simulated situations	HTTP REST

Client component	Access description	Access protocol
Lean Construction Platform	Renovation status	TBD
Job Scheduler Optimizer	TBD	TBD
PPE Monitoring System	Push alerts/reports from safety components	HTTP / MQTT
Anti-Collision System	Push alerts/reports from safety components	HTTP / MQTT
Area Boundary System	Push alerts/reports from safety components	HTTP / MQTT
Environmental Monitoring System	Periodic reports of statistical analysis	HTTP
Waste Tracking and Management	Push reports	HTTP

Write access to components

Target component	Access description	Access protocol
Digital Building Logbook	Store reports (human readable)	HTTP
Eclipse SensiNact Platform (DiTi)	Notification of alerts Store reports (values)	HTTP / MQTT

4.2.1.8 AR/VR Training Suite

Owner	Component group
CERTH	InCUBE Retrofitting Guide (R-GUIDE)

The AR/VR Training Suite is a component of the InCUBE Retrofitting Guide (R-Guide), which is capable of providing training to the workers, either "off-line" or on-site ("on-the-job" training), based on Augmented Reality (AR) techniques. The goal is to increase worker safety and satisfaction and accelerate the learning process compared to traditional techniques. The training packages that will be developed will focus on training both novice workers as well as experienced workers in the use of the new technologies, novel equipment, and construction techniques of the InCUBE Deep Renovation Pool of Solutions.

The integration of the AR/VR Training Suite with the Resilience Dashboard will allow to inform the workers by sending notifications and warnings to be shown in the AR environment and also present information on the Resilience Dashboard (e.g., on training progress). The tool has the potential to decrease the errors and faults during the renovation processes, while serious delays can be avoided with the use of "on-the-job" assistance resulting in cost savings.

Input

Input origin	Access description	Input Format
Modular BIM/CIM platform	3D representation of the building 3D representation of BIM assets	IFC File
Resilience Dashboard	Processes definitions, Event data, Notifications for the user	JSON
Digital Building Logbook	Processes definitions, Training material of products with guidelines, and building's assets	HTTP REST

Read access to components

Target component	Access description	Access protocol
Resilience Dashboard	Feedback report on training progress	HTTP REST
Renovation Marketplace	Online assistance communication	HTTP REST / WebRTC
Digital Building Logbook	Training status and history per user	HTTP REST
Modular BIM/CIM Platform	3D representation of buildings and assets	HTTP

Access by other components

Client component	Access description	Access protocol
Renovation Marketplace	Online assistance communication, Training status	HTTP REST

Write access to components

Target component	Access description	Access protocol
Digital Building Logbook	Store training reports	HTTP
Renovation Marketplace	Online assistance communication	HTTP REST / WebRTC
Resilience Dashboard	Notifications and warnings to the user (e.g., related to safety) to be visualised in AR	HTTP REST

4.2.1.9 Lean Construction Platform

Owner	Component group
CIRCE	InCUBE Workflow Integrator and Optimizer (WINER)

The Lean Construction Platform (LCP) is a web-based collaborative platform, built upon the concept of Integrated Project Delivery (IPD), allowing information exchange and organization among multiple stakeholders of the renovation value chain. CIRCE's LCP is able to compile and manage: a) BIM information; b) information from products' digital twins; c) monitoring data from product manufacturers; d) monitoring data from demolition/retrofitting.

At the time of the redaction of this document, the organisation of the workflow is not yet completely defined. Common protocols are expected to be used in the exchange of information (either through APIs or queries to databases). The specific inputs of this module still need to be detailed in depth.

Input

Input description	Comment
Data from product manufacturers	Pending definition of the information that will be needed
Monitor data from demolition/retrofitting	Pending definition of the information that will be needed

Read access to components

The Lean Platform will retrieve information from the following components:

Target component	Access description	Access protocol
Modular BIM/CIM platform	Information about BIM Models	HTTP/DB queries
Eclipse SensiNact Platform	Current status	HTTP
P-GUIDE	Retrieve the optimal renovation scenario	HTTP/DB queries
Job Scheduling Optimizer	Optimal sequence of actions of various scenarios	HTTP/DB queries
Resilience Dashboard	TBD	TBD

Access by other components

Client component	Access description	Access protocol
Job Scheduler Optimizer	TBD	TBD
Resilience Dashboard	TBD	TBD
VERIFY	TBD	TBD

Write access to components

Target component	Access description	Access protocol
Job Scheduling Optimizer	Internal information about scheduled actions	HTTP/DB queries (?)
Resilience Dashboard	TBD	HTTP/DB queries (?)

4.2.1.10 Job Scheduling Optimizer

Owner	Component group
CERTH	InCUBE Workflow Integrator and Optimizer (WINER)

The Job Scheduling Optimizer (JSO) is an online tool, generating the optimal construction/renovation actions sequence, in terms of time and cost efficiency, according to the selected constraints and preferences (e.g., energy consumption, cost reductions, available workers, precedence relations between activities). JSO is accompanied by an interactive user interface, which allows users to provide their preferences. JSO can reduce construction time and costs by 6-20% in comparison with random work allocation for a specific renovation scenario.

Input

Input origin	Access description	Input Format
File upload	Manual provision of content	CSV

Read access to components

Target component	Access description	Access protocol
Lean Construction platform	Internal information about scheduled actions	TBD
Eclipse SensiNact Platform	Real time sensor data	HTTP / MQTT
P-GUIDE (Dynamic Decision-Making Tool)	Retrieve the optimal renovation scenario	HTTP
Resilience Dashboard	Value chain processes to be scheduled	HTTP

Access by other components

Client component	Access description	Access protocol
P-GUIDE	TBD	TBD
Lean Construction Platform	TBD	TBD
VERIFY	TBD	TBD
Resilience Dashboard	TBD	TBD

Write access to components

Target component	Access description	Access protocol
Lean Construction platform	Internal information about actions to be scheduled	TBD
P-GUIDE (Dynamic Decision-Making Tool)	Optimal sequence of interventions	HTTP
Resilience Dashboard	Optimal sequence of value chain processes	HTTP (under evaluation)
Digital Building Logbook	Optimal sequence of actions of various scenarios	HTTP

4.2.1.11 Renovation Marketplace

Owner	Component group
CERTH	InCUBE BUSINESS Innovations supporting NEW ENTRANTS

The InCUBE Renovation Marketplace is the main platform of the InCUBE One-Stop-Shop, where the product and process innovations and business models will be digitally available, and various stakeholders (e.g., workers, engineers, technology providers, buildings owners) will be able to communicate and react among each other. Moreover, users will be able to monitor the overall renovation project flow and the building operations. By utilising training material and modules, the users will be able to enrich their knowledge on various deep renovation related aspects and assist workers on the site (knowledge sharing).

The Renovation Marketplace will be an open format web tool and will also support Technical and Innovation management, serving as an up-to-date pool of relevant technologies. It can be used by third parties, who will be able to use and access the project results and include their technologies as well. It will include information on novel envelope and construction materials solutions, energy systems, advanced HVAC systems, retrofitting process improvement techniques, Business Models, a dashboard & training material (developed within WP6).

Input

Input origin	Access description	Input Format
Digital Building Logbook	Information on renovation works. Information on materials, products, and processes	JSON (HTTP REST)
Modular BIM/CIM Platform	Retrieve the list of available BIM assets	File / JSON (HTTP REST)
Resilience Dashboard	Integration for visualisation	JSON (HTTP REST)

Read access to components

Target component	Access description	Access protocol
AR/VR Training Suite	TBD	TBD
Digital Building Logbook	Get updates of descriptions of products/technologies	HTTP REST
Module BIM/CIM Platform	Update the list of available BIM assets	File / JSON (HTTP REST)

Access by other components

Client component	Access description	Access protocol
AR/VR Training Suite	Online assistance communication	HTTP REST / WebRTC
Digital Building Logbook	Addition of descriptions of new products/technologies	HTTP REST

Write access to components

Target component	Access description	Access protocol
AR/VR Training Suite	Online assistance communication	HTTP REST / WebRTC
Digital Building Logbook	TBD	HTTP

4.2.2 Energy Management Systems

This section describes the different Energy Management Systems (EMS) that will be deployed on the different demonstration sites.

4.2.2.1 Energy Cloud EMS – Spanish Demo Site

Owner	Component group
CIRCE	InCUBE Building-to-X Smart Energy Manager (B2X-S-EMS)

CIRCE ENERGY CLOUD applies the performance of an industrial SCADA system to the Building Energy Management, being able to collect Energy Data from many different hardware devices and enabling to visualize the Energy consumption the building in an intuitive and simple way via the 3D BIM model.

Input

Input origin	Access description	Input Format
Energy Data	Energy consumption/production data	HTTP
Comfort devices	Comfort data	MQTT
Modular BIM/CIM Platform	Building information and 3D structure	HTTP

Read access to components

Target component	Access description	Access protocol
Modular BIM/CIM Platform	Building information and 3D structure	HTTP

4.2.2.2 Smart Building EMS (S-BEMS) – Italian and Dutch Demo Site

Owner	Component group
TERA/FBK	InCUBE Building-to-X Smart Energy Manager (B2X-S-EMS)

This solution is an integrated Building Monitoring System (BMS) that moves beyond business-as-usual BEMS by: a) applying Machine Learning (ML) and deep neural network algorithms to significantly improve forecasting of energy consumption and RES production, with special emphasis given on the maximization of self-consumption towards the establishment of an Energy Community; b) ensuring interoperability with a multitude of third party hardware systems through the support of most key IoT protocols (e.g. MQTT, REST, etc.) and Building Automation protocols (e.g. BACnet, Modbus, KnX, ZigBee, ZWave, M-Bus, LoRa) as well as with third parties open software applications (both free of charge or licensed) that could extend the set of offered services and functionalities. The S-BEMS is highly cost-efficient (PBT=1-2 years).

The current version of S-BEMS was also adopted to support energy diagnosis for industrial buildings, residential and commercial, where during InCUBE it will be advanced with the aim to better serve the needs of renewable energy communities and real time energy flexibility services. More specifically, BEETA™ MoCo and/or GioE IoT edge computer will be upgraded to enhance the S-BEMS aiming at enhancing the electric energy flow management systems in smart grids and energy communities. The S-BEMS – powered by FBK algorithms – will be adapted to interact with the district energy management or aggregation platforms developed by partner EVOLVERE through the development of relevant energy rules and logic. Advancements will comply with Directive 2014/53/EU (RED, Radio Equipment Directive) and ROHS.

Input

Input origin	Access description	Input Format
Modular BIM/CIM Platform	Building information and 3D structure	IFC
Building AIR sensing devices	Indoor Air parameter	BACnet, Modbus, KnX, ZigBee, ZWave, M-Bus, LoRa
Building IEQ sensing device	Indoor Environmental Quality parameters	BACnet, Modbus, KnX, ZigBee, ZWave, M-Bus, LoRa
Building Electrical Energy Meters	Electrical Energy consumption (both measured and fiscal) data	Power Line Communication (PLC) for the Italian pilot only, MQTT
EvoDistrict	Energy consumption/production data	MQTT JSON

Read access to components

Target component	Access description	Access protocol
Modular BIM/CIM Platform	Building information and 3D structure	HTTP

Access by other components

Client component	Access description	Access protocol
EvoDistrict	Energy consumption Production data	MQTT JSON

Write access to components

Target component	Access description	Access protocol
EvoDistrict	Application of rules to be used by the ML algorithms	MQTT JSON
Eclipse SensiNact Platform	Push sensor data	HTTP / MQTT

4.2.2.3 District EMS (EvoDistrict) – Italian Demo Site

Owner	Component group
EVOLVERE/FBK	InCUBE Building-to-X Smart Energy Manager (B2X-S-EMS)

EvoDistrict is a cloud-based platform for the integration and optimal management of distributed energy (generation, storage, and consumption) within a district; combining Blockchain and Cloud-Computing technologies. EvoDistrict unlocks services such as generation and load forecasting, creation of baselines, internal flexibility optimization (day head and real time) and the calculation of bids for participating to the ancillary service markets. It effectively allows to remotely control the charge/discharge of residential battery storages, while ensuring the maximization of self-consumption for the individual user.

EvoDistrict has been updated during the last years under the framework of Italian national projects (ComESto, UVAM) and has been field-tested in its current form. During InCUBE it will: a) improve the current optimization models of a virtual aggregate of energy users, as well as the development of new, more effective models; b) improve the collection process of data sent by a wide variety of monitoring and controlling devices, supporting, and implementing almost all open communication protocols, non-open or proprietary protocols; c) ensure interconnectivity with the TERA S-BEMS. Advancements will comply with standards relevant to Infrastructure as a service (IaaS); VMware virtualization technology; System Development Life Cycle (SDLC); BackOffice Web interface; HTTP; WebSocket; MQTT; JSON.

Input

Input origin	Access description	Input Format
Energy Devices	Energy consumption Production Data	*Aims to support as many protocols as necessary*

Read access to components

Target component	Access description	Access protocol
S-BEMS	Energy consumption Production data	MQTT JSON

Access by other components

Client component	Access description	Access protocol
S-BEMS	Push energy consumption Production data	MQTT JSON

Output

Target component	Access description
Energy Devices	Control

4.2.3 Safety components

Those components are related to the security of persons either working on the renovation building site or passing by it.

4.2.3.1 Personal Protective Equipment (PPE) Monitoring System – Italian and Spanish Demo Site

Owner	Component group
RINA-C	Solutions supporting On-Site Installation and Automation

This solution monitors correct use of PPE devices by operators. It is based on android Apps installed on smartphones, enabling verification of proper use of PPE (helmet, harness, shoes, etc.) through continuous monitoring of Bluetooth Low Energy tags installed on the PPE. It also monitors man down and dynamic shock detection, indoor and outdoor geo-localization of workers, and monitoring of operating status (battery level, etc.).

This solution is meant to work only with the Resilience Dashboard. The raw sensor data will not be available: only reports will be sent to the resilience dashboard. The reports will be aggregated and anonymized.

Input

Input origin	Access description	Input Format
Wearable sensors	Check presence of sensors near workers	TBD

Write access to components

Target component	Access description	Access protocol
Resilience Dashboard	Reports on safety rules compliance	HTTP

4.2.3.2 Anti-Collision System (ACS) – Italian and Spanish Demo Site

Owner	Component group
RINA-C	Solutions supporting On-Site Installation and Automation

This solution prevents the risk of collision between workers and machines, notifying the driver in real time with a visual and acoustic alarm in the presence and position of pedestrians. Among other functionalities, ACS can display the operator's position around the vehicle, historizes and analyses detections, enables alarm threshold warning and pre-warning and supports geofencing functionalities.

This solution is meant to interact only with the Resilience Dashboard component.

Input

Input origin	Access description	Input Format
Sensors	Detection of risk of collision	TBD

Write access to components

Target component	Access description	Access protocol
Resilience Dashboard	Reports on detections of risk of collisions	HTTP / MQTT

4.2.3.3 Area Boundary (AB) System – Italian Demo Site

Owner	Component group
RINA-C	Solutions supporting On-Site Installation and Automation

This solution monitors the presence of personnel in one or more operating dangerous areas. The system has a multi-reading capability, in addition to a great detection range. AB can be linked with a control room that provides, in real time, an overview of the situation and the position and identity of each operator.

The area definition relies on on-site delimiters and does not require to be linked to a BIM description.

This solution is meant to interact only with the Resilience Dashboard component.

Input

Input origin	Access description	Input Format
Presence Sensors	Detect the presence and location of persons in specific areas	TBD

Write access to components

Target component	Access description	Access protocol
Resilience Dashboard	Notification of presence in specified area	HTTP / MQTT

4.2.4 Data providers

The providers described here are data sources for the software components. They are not shown in the schema for readability reason. All the providers in this section are providing BIM information to be stored in the Modular BIM/CIM platform.

4.2.4.1 Terrestrial laser scanning (TLS), inspection and 3D modelling

Owner	Component group
FBK	Solutions supporting On-Site Installation and Automation

This solution refers to the utilization of a framework to derive 3D information of buildings in urban areas by means of UAV/drone platforms and on-board sensors (cameras or LiDAR instruments). The framework offers data acquisition and 3D processing over urban areas (from single buildings to neighbourhoods). UAV-based inspection and 3D modelling can also be used for structural analyses, monitoring of solar panels, thermographic studies, etc.

The result of the scanning will be used to enhance the BIM description of the building stored in the BIM/CIM platform. The scanning data itself is not expected to be stored neither in the logbook nor the BIM/CIM platform.

4.2.4.2 Drone-enabled Scan-to-BIM 3D modelling

Owner	Component group
VW	InCUBE Sophisticated Digital Twin Engine (DiTi)

This solution refers to the creation of point clouds by drone technology (such as Lidar) equipped with 3D scanners. The specific process is much quicker than conventional surveying methods and results in a very high accuracy of the developed 3D model. The solution is compliant with NEN-&-ISO 19650 and is highly suitable for cultural heritage buildings, where a major challenge is coping with deviations that cannot be identified in existing building plans.

The result of the scanning will be used to enhance the BIM description of the building stored in the BIM/CIM platform. The scanning data itself is not expected to be stored neither in the logbook nor the BIM/CIM platform.

4.2.4.3 Laser 3D scanning and UAV-based aerial georeferenced photogrammetry

Owner	Component group
METRO7	InCUBE Sophisticated Digital Twin Engine (DiTi)

This solution improves the architectural project development and drafting process. Data collection using Laser Scanner allow accuracy improvement and times reduction. Modelling with BIM tools improve communication and connection, workflows, and design. The solution complies with IFC (ISO 16739-1:2018) and gbXML formats which are interoperable and standardized BIM formats.

The result of the scanning will be used to enhance the BIM description of the building stored in the BIM/CIM platform. The scanning data itself is not expected to be stored neither in the logbook nor the BIM/CIM platform.

4.2.4.4 BIM-based Design of Prefab Modules

Owner	Component group
VW	Solutions supporting Off-Site Manufacture

This solution refers to the re-design of the construction process of prefab modules by producing modules that require no further work at the building site other than assembly – these are fitted with windows, electrical wiring, plumbing and carpentry throughout the assembly line. Modules' assembling lines are digital by design – offering products, which are designed and generated according to the client's preferences, through interactive platforms.

Output data

Target component	Data description
Modular BIM/CIM Platform	Description of building modules

4.2.4.5 Modular Facades with Integrated Building Elements

Owner	Component group
KOVER	Envelope – Material Solutions

This solution is a lightweight (30% lighter in comparison with other similar solutions), modular (different building elements such as external lifts, balconies and windows can be integrated) construction system for the rehabilitation of residential buildings with the aim of improving their energy performance. The system allows the use of any material to adapt the facades finish to the will of the designers and urban planning requirements, which makes it potentially applicable to protected buildings.

Output data

Target component	Data description
Modular BIM/CIM Platform	Description of building modules

4.2.4.6 K-ROCK CNX - highly efficient insulation material with the A1 fire reaction class.

Owner	Component group
K-FLEX	Envelope – Material Solutions

The major advantage of K-FLEX® K-ROCK CNX is its ability to reduce thermal bridges on connection. Unlike standard materials, this product can be prepared in a way that minimizes the formation of thermal bridges, which are areas where heat can escape from the insulation and reduce its effectiveness. This is achieved by cutting the blocks in a unique way, so that there is no thermal bridge on the width side.
Another advantage is that block of MW can be cut in every dimension. Only one dimension is stable - Width - it is 100 cm. Length can be ordered from the range of 10 to 2400 mm. In this case, if we have an exact specification of the material from the construction side, we can theoretically eliminate scrap on the construction side (zero scrap).

Output data

Target component	Data description
Modular BIM/CIM Platform	Description of building modules

4.2.4.7 BIPV pre-installed on Prefab Facades

Owner	Component group
WEBO/VW	RES Generation Solutions

This solution refers to the development of a prefabricated façade system with integrated photovoltaics for energy production purposed for renovation of high-rise dwellings/apartment buildings. The system takes advantage of the vertical space on facades to generate solar energy (150 Wp/m2), whereas prefabrication of integrated solutions reduces CO_2 impact by incorporating a circular demountable connection design. Savings up to 20% of PV façade installation costs can also be achieved.

Output data

Target component	Data description
Modular BIM/CIM Platform	Description of building modules

4.2.4.8 Hybrid Thermal Solar Panels (BI-SHE)

Owner	Component group
ABORA	RES Generation Solutions

This innovative solution is a "Prefabricated Active Modular Roof", that is, a prefabricated system that resolves in a module the solar production for the building by means of BI-SHE (Building Integrated - Solar Heat and Electricity) Hybrid Solar Panels, in combination with photovoltaic panels, covering part of the building's demand for heat and electricity through renewable energies. Each module will consist of the necessary structure to house the panels and will be able to fix them directly to the roof, thus reducing time and costs of on-site installation. In addition, this module will also have the prefabricated technical enclosed space to place the rest of the required elements for its operation (tanks, pumps, inverters, DC/AC panels and other auxiliary components).

Output data

Target component	Data description
Modular BIM/CIM Platform	Description of building modules

4.2.4.9 Tegosolar® BIPV Shingles

Owner	Component group
TEGOLA	RES Generation Solutions

This solution refers to the utilization of bituminous-based PV shingles suitable for complicated building roof geometries where traditional PVs are difficult to install. The shingles' slim design, flexibility, high temperature endurance, class1 fire certification and, most importantly, light weight (12 kg/m2, 20% less in comparison with traditional PVs), can accommodate many roof types. Cells are made of triple-junction thin-film amorphous silicon absorbing blue, green, and red light through 3 separate layers. PV cells thus produce energy with direct light as well as in diffuse light conditions. Bypass diodes between cells allow the module to produce energy even when it is partially in the shade. The solution does not utilize metallic frames, thus providing a very low visual impact, is not subject to wind load, is not composed of reflective materials and can easily be installed by a trained asphalt shingle roofer.

Output data

Target component	Data description
Modular BIM/CIM Platform	Description of building modules

4.2.5 Actuators

4.2.5.1 BIM-connected Robotic Systems

Owner	Component group
VW	Solutions supporting On-Site Installation and Automation

This solution refers to the utilization of highly innovative robotic systems including: a) BIM-connected demolition robot to automate the demolition process (e.g., facades) and attain a higher process speed ; b) BIM-connected telescopic crane, for installing facades so as to avoid scaffolding (constructing safe scaffolding is highly time-consuming and most building-related accidents take place on scaffolding); c) BIM-connected drilling robot optimizing drilling for renovation purposes (e.g. cable wiring and pipelines), which enables savings of up to 30% of execution time and up to 40% of raw material requirements. The robot can drill up to 800 holes a day without any physical effort. All these robots are fully equipped with warning sensors to minimize any unexpected damage of the surroundings (e.g., due to human error), which makes them an excellent choice for potentially renovating cultural heritage buildings.

Input

Input origin	Access description	Input Format
Modular BIM/CIM Platform	Description of the buildings	IFC

4.2.5.2 Construction Waste Sorting Robot

Owner	Component group
VW	Solutions supporting Circular Construction

This solution refers to the utilization of a robot for scanning and separating waste facilitating recycling and reducing material disposal – located in the construction site. The sorting robot is stationed outside the renovated building so it can be applied to any building typology.

Input

Input origin	Access description	Input Format
Modular BIM/CIM Platform	Description of the buildings	IFC

4.2.6 Tracking/Monitoring components

4.2.6.1 Waste Tracking and Management

Owner	Component group
RINA-C	Solutions supporting Circular Construction

This solution comprises an open waste management system for managing logistics and traceability of different types of waste. Waste traceability is implemented through a blockchain-encryption system in which all flows are certified. The system enables the management of both CDW (Construction and Demolition Waste) and non-CDW (e.g., hazardous domestic waste and bulky waste); for CDW a dedicated platform can estimate the CDW waste quantities that can arise from a demolition project by providing possible utilization options and related logistic references: automatically, by using BIM models, or by inputting design data through a wizard.

Input

Input origin	Access description	Input Format
Modular BIM/CIM Platform	Building description	IFC

Write access to components

Target component	Access description	Access protocol
Resilience Dashboard	Reports	HTTP

4.2.6.2 Environmental Monitoring System

Owner	Component group
RINA-C	Solutions supporting Circular Construction

This solution collects environmental data on emissions from field sensors. It integrates the following streams: i) Energy Monitoring ii) Fuel consumption Monitoring iii) Environmental Management and

Waste Management consumption and treatment, and iv) Stationary emission monitoring. AI algorithms and ML techniques are used to compare the monitoring results to a baseline, considering also meteorological conditions, and others.

Input

Input origin	Access description	Input Format
Sensors	Sensor data collection	

Write access to components

Target component	Access description	Access protocol
Resilience Dashboard	Periodic reports of statistical analysis	HTTP

4.2.7 Methodology Components

4.2.7.1 IPD, A3 and LPS-driven Rehabilitation

Owner	Component group
METRO7	InCUBE PROCESS Innovations supporting INDUSTRIALIZATION of renovation

The specific solution refers to the application of Lean methodology for the rehabilitation process. It combines Integrated Project Delivery (IPD) work processes, development of A3 report models based on PDCA to reflect problems and solutions for future actions, and continuous improvement and application of Last Planner System (LPS) for the work planning. A3 reports collect background, current situation, cause analysis, improvement actions, action plans and results monitoring. LPS is a planification methodology that promotes detailed communication between all stakeholders preventing issues becoming critical.

4.3 Summary of links between software components

4.3.1 List of software components

Table 4 is a reminder of the components listed in section 4.2, associated to their group.

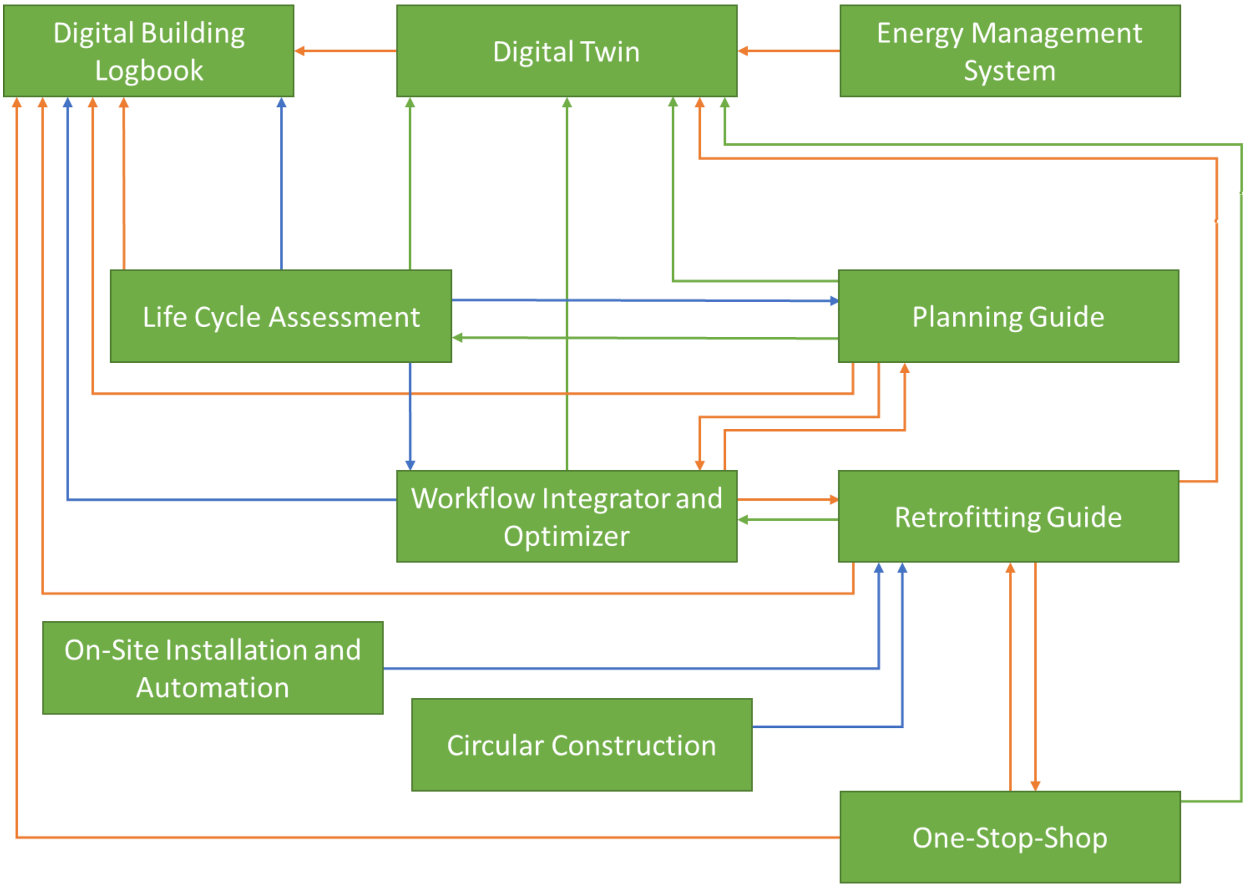
Component	Component Group	Owner
Digital Building Logbook	Digital Building Logbook	CERTH
Modular BIM/CIM Platform	Digital Twin	CIRCE
Eclipse SensiNact Platform	Digital Twin	KENT

INTEMA	BIM2BEM LCA	CERTH
VERIFY	BIM2BEM LCA	CERTH
InCUBE Planning Guide	P-GUIDE	CERTH
Resilience Dashboard	R-GUIDE	RINA-C
AR/VR Training Suite	R-GUIDE	CERTH
Lean Construction Platform	WINER	CIRCE
Job Scheduling Optimizer	WINER	CERTH
Renovation Marketplace	One-Stop-Shop	CERTH
Energy Cloud EMS	B2X-S-EMS	CIRCE
Smart Building EMS (S-BEMS)	B2X-S-EMS	TERA/FBK
District EMS (EvoDistrict)	B2X-S-EMS	EVOLVERE/FBK
PPE Monitoring System	On-Site Installation and Automation	RINA-C
Anti-Collision System	On-Site Installation and Automation	RINA-C
Area Boundary System	On-Site Installation and Automation	RINA-C
Environmental Monitoring System	Circular Construction	RINA-C

Table 4 - Software Components

4.3.2 Functional-level architecture

The following figure gives a give overview of the links between the various groups of software components. The arrow indicates that the tail (source) interacts with the head (target) in read and/or write mode.

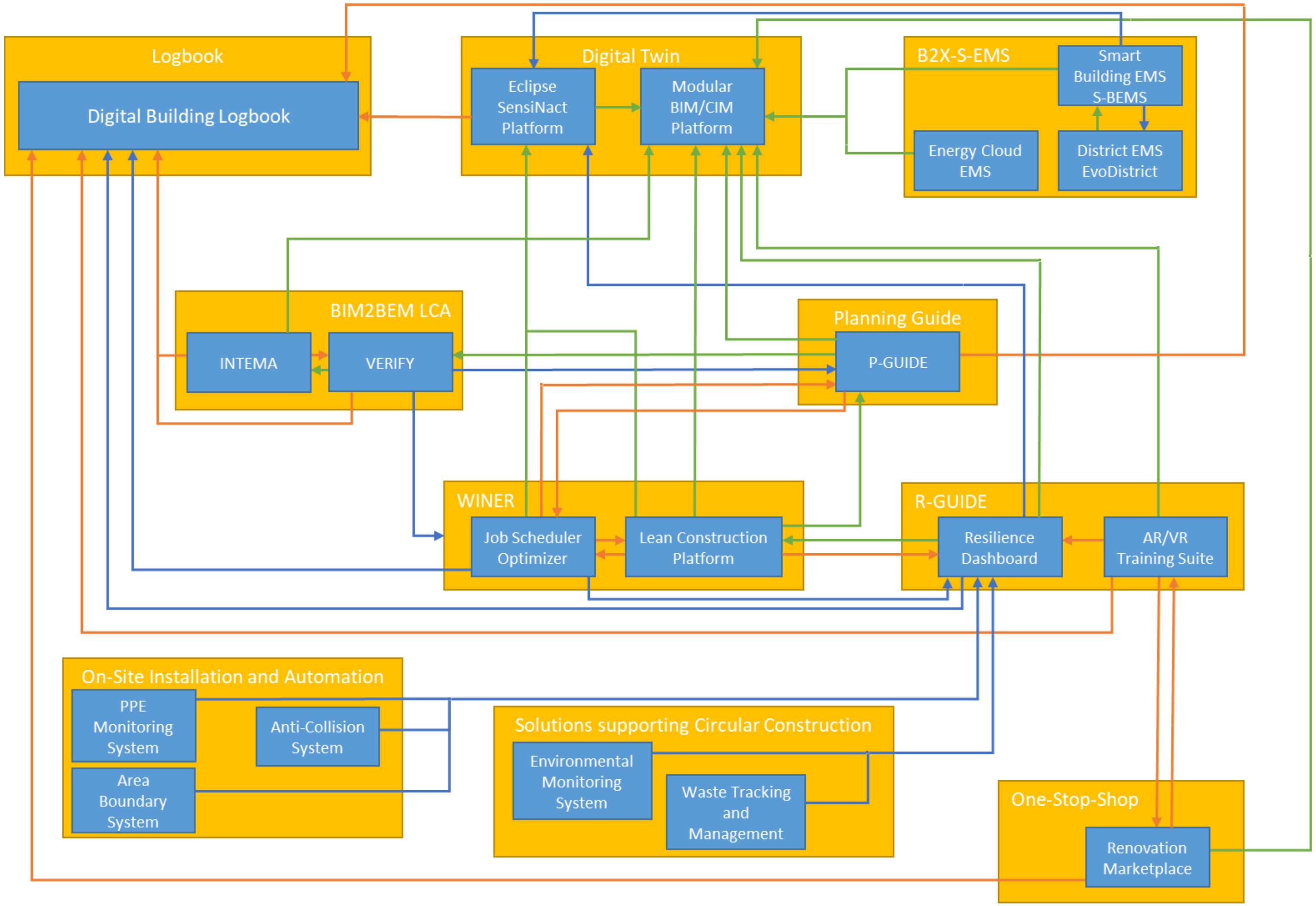


Green: Read; Blue: Write; Red: Read & Write; Gray: Possible connections

Figure 5 - Global architecture overview

4.3.3 Software component-level architecture

Figure 6 gives a give overview of the links between the various groups of software components. The arrow indicates that the tail (source) component interacts with the head (target) component in read and/or write mode. The arrow represents the interaction source and the colour the data direction. On the other hand, Figure 7 shows the data flow between components, instead of the component requesting or writing the data.



Green: Read; Blue: Write; Red: Read & Write

Figure 6 - Software Components Interactions

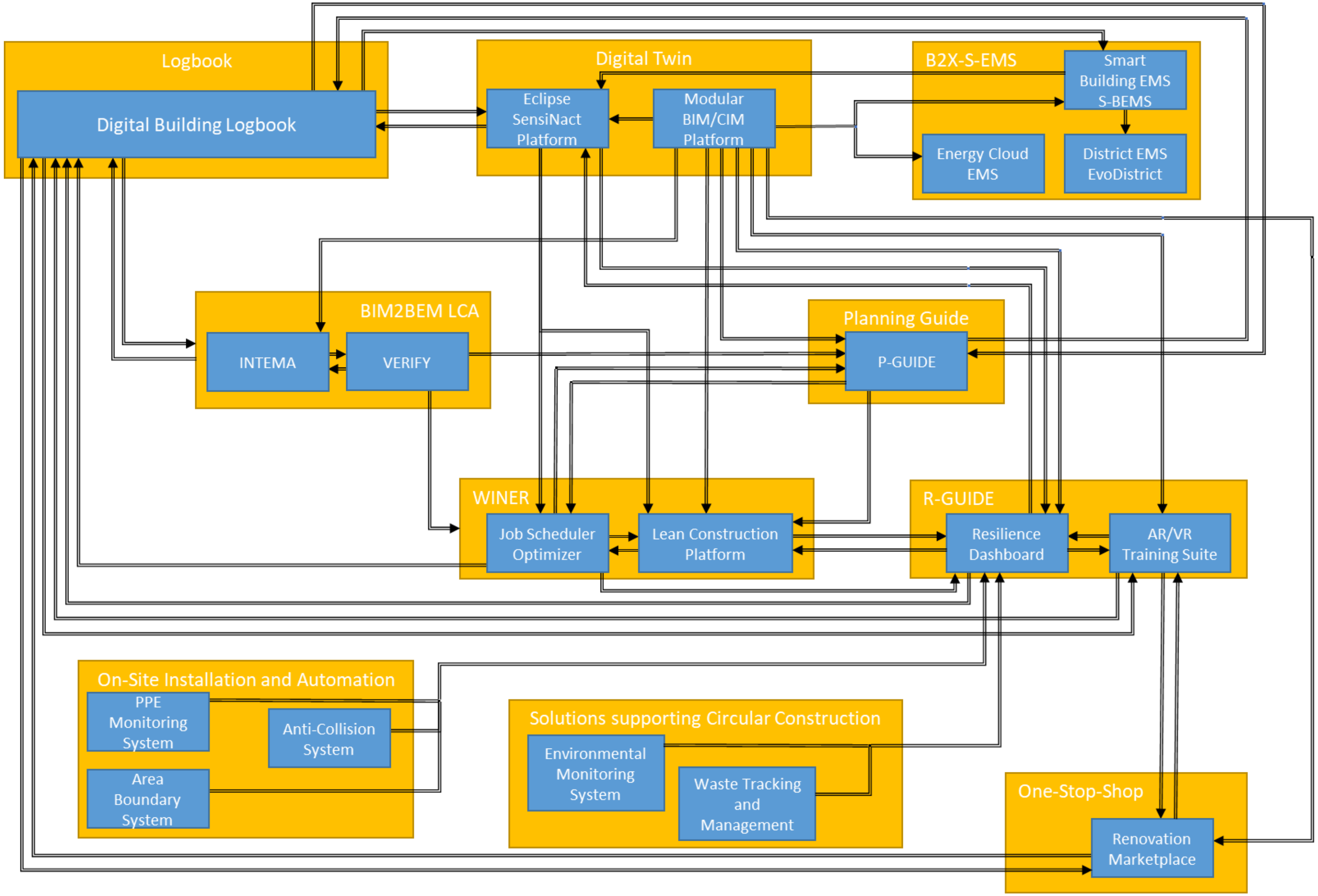


Figure 7 - Data flow between components

4.4 Components interactions

Table 5 shows the adjacency matrix of the common InCUBE components found in all demonstration sites showing the kind of access the components on the left side require over the components on the top.

Row component access to column component	Digital Building Logbook	Modular BIM/CIM Platform	Eclipse SensiNact Platform	INTEMA	VERIFY	P-GUIDE	Resilience Dashboard	AR/VR Training Suite	Lean Construction Platform	Job Scheduling Optimizer	Renovation Marketplace	Energy Cloud EMS	Smart Building EMS S-BEMS	District EMS (EvoDistrict)	PPE Monitoring System	Anti-Collision System (ACS)	Area Boundary (AB) System	Waste Tracking and Management	Environmental Monitoring System
Digital Building Logbook																			
Modular BIM/CIM Platform																			
Eclipse SensiNact Platform	R W	R																	
INTEMA	R W	R			R W														
VERIFY	R W			R		W			W	W									
P-GUIDE	R W	R			R					R W									
Resilience Dashboard	W	R	W						R										
AR/VR Training Suite	R W	R					R W				R W								
Lean Construction Platform		R	R			R	R W			R W									
Job Scheduling Optimizer	W		R			R W	W		R W										
Renovation Marketplace	R W	R						R W											
Energy Cloud EMS		R																	
Smart Building EMS S-BEMS		R	W											W					
District EMS (EvoDistrict)													R						
PPE Monitoring System							W												
Anti-Collision System (ACS)							W												
Area Boundary (AB) System							W												
Waste Tracking and Management							W												
Environmental Monitoring System							W												

Values in the table are R: Read-Only, W: Write-Only, RW: Read/Write.

Table 5 - Adjacency Matrix of common InCUBE components

4.5 Components integration guidelines

This section gives some advice on the implementation of links between components according to what has been described for each of them. The following table should be considered guidelines instead of absolute rules as some integration requirements might evolve faster than this document.

Table 6 - Integration Guideline Description

Ref	Integration Guideline Description
IG1	Use similar network protocols over the project. Most of the components are intended to be accessed via: • HTTP to access static files, • HTTP REST to access APIs, • WebSocket for API subscriptions, • MQTT for sensor updates. This list is not exhaustive, but adding non-standard or proprietary protocols should be discussed.
IG2	Data, payloads, and files should be transferred using a protocol and a format that doesn't require a specific consumer technology (e.g., use a JSON representation instead of Java Serializable Format).
IG3	All public APIs should be documented. Components providing REST APIs should be accompanied by an OpenAPI[2] description. Components providing WebSocket and MQTT endpoints should be described using the AsyncAPI[3] specification. Other protocols should be described either following the OpenAPI or AsyncAPI specification, or by providing a readable Markdown file describing accesses and payloads.
IG4	Components exchanging files must agree on supported file formats. Open standards should be preferred, but proprietary file formats are allowed if supported by both components.
IG5	Operations requiring a date, time, duration, or time interval information should follow the ISO 8601 standard. All time-related strings must either contain an explicit time offset from UTC or be considered UTC. Local time should be avoided in APIs.
IG6	Each component should be associated to a set of tests validating its own access points. Those tests can be used as examples for IG3.
IG7	Each component should be associated to a set of integration tests validating its accesses to the components it works with.

[2] https://spec.openapis.org/oas/latest.html
[3] https://www.asyncapi.com/docs/reference

IG8	When applicable, components should interact using similar ontologies. Components requiring a transformation should document it explicitly.
IG9	Components should share security credentials and rights managements to ease user interactions. This can be done either by configuration (secrets sharing) or by centralized authentication (token-based).

5 Readiness Levels

To evaluate the progress in the development of the different components of the architecture, and moreover, the progress in their integration, the InCUBE project will follow a metric-based approach. This methodology presented below will enable to follow progress and evaluate the readiness of the components and the system as a whole. It will be used in the integration work of WP3 and WP5 and will eventually also provide guidance on potential exploitation opportunities for WP9.

5.1 System Readiness Level methodology

The methodology used by the InCUBE project aim at evaluating the readiness of components individually but also how they interact with each other. Different metrics will be used for these assessments.

5.1.1 Individual component evaluation

The InCUBE project will follow the Technology Readiness Level (TRL) approach to evaluate the readiness of each individual component of the architecture.
The project uses the TRL scale as defined by Horizon Europe in the general annexes.

Table 7 - Technology Readiness Levels

TRL	Definition
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in a lab
5	Technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
6	Technology demonstrated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in an operational environment
8	System complete and qualified
9	Actual system proven in an operational environment (competitive manufacturing in the case of key enabling technologies, or in space)

To evaluate the TRL of the components, the main responsible partner will provide a self-assessment of the TRL. This self-assessment will be done following the guidelines of the "TRL self-assessment tool" defined by the BRIDGE2HE project[4].

The project partners will collectively proceed to a peer review of the TRL self-assessment (under coordination of the Project Innovation Manager) to ensure coherence of the different self-assessment across the partners and project activities.

5.1.2 Integration evaluation

Despite the utility and value of the TRL as a metric for determining technology maturity before transitioning into a system, TRLs were not intended to address systems integration nor to indicate that the technology will result in successful development of a system. Thus, to evaluate how these different components are integrated in the InCUBE project, we used the Integration Readiness Level (IRL) and System Readiness Level (SRL) approach. While TRL give an indication on components maturity, IRL[5] gives an indication on the maturity of interactions between components and SRL provides an indication of maturity of the whole system.

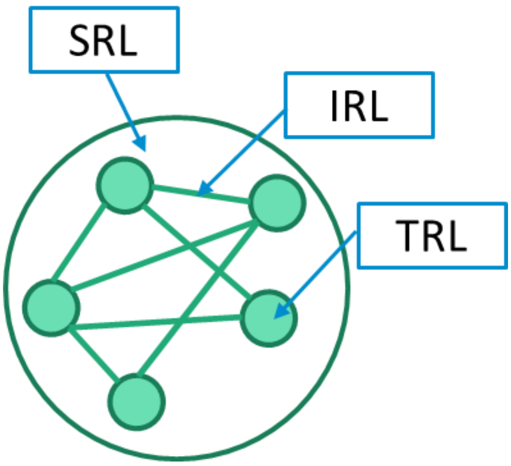


Figure 8 - Relation between TRL, IRL and SRL

[4] Guiding notes to use the TRL self-assessment tool, BRIDGE2HE project, available online: https://horizoneuropencpportal.eu/sites/default/files/2022-12/trl-assessment-tool-guide-final.pdf

[5] Sauser, Brian & Verma, Dinesh & Ramirez-Marquez, Jose & Gove, Ryan. (0002). From TRL to SRL: The concept of systems readiness levels. Conference on Systems Engineering Research

The following table presents the scale of the Integration Readiness Levels used to measure the 1-1 integration of each component of the platform.

Table 8 - Integration Readiness Levels

Integration Readiness Levels	
0	No integration needed
1	An interface (i.e., physical connection) between technologies has been identified with sufficient detail to allow characterization of the relationship
2	There is some level of specificity to characterize the interaction (i.e., ability to influence) between technologies through their interface
3	There is Compatibility (i.e., common language) between technologies to orderly and efficiently integrate and interact.
4	There is sufficient detail in the quality and assurance of the integration between technologies
5	There is sufficient control between technologies necessary to establish, manage, and terminate the integration.
6	The integrating technologies can accept, translate, and structure information for its intended application
7	The integration of technologies has been verified and validated with sufficient detail to be actionable.
8	Actual integration completed and Mission Qualified through test and demonstration in the system environment.
9	Integration is Mission Proven through successful mission operations.

The evaluation of the Integration Readiness Levels between the different components will be done through a coordinated self-assessment process. Each owner of each component will provide a self-assessment of its component integration level respective to the other components of the architecture. Differences in evaluations of integration levels between two components will be reconciliated and homogenized through a concertation process led by the project Innovation Manager.

This evaluation will be done regularly throughout the project to evaluate progress in integration.

5.1.3 System Readiness assessment

To evaluate the overall readiness of the integrated system, InCUBE will use the SRL metric.

SRL is calculated from TRL and IRL. The steps are the following:

- TRL and IRL matrix normalisation (all values are divided by 9)
- Matrix product of the IRL matrix by the TRL vector
- Division of each value of each vector value by the link number of the component plus one (it is considered that the component has a link with itself).
- Sum of the values of the resulting vector
- Division of the resulting value by the number of components in the system.

- Assessment of the SRL level by comparing the value obtained at the limit of each level.

As such, SRL can be also presented through the following formula:

$$\frac{\sum_{0}^{nb\_component} \frac{\sum_{0}^{nb\_link} IRL \times TRL}{nb_{link} + 1}}{nb\_component}$$

The following table presents the SRL scale.

Table 9 - System Readiness Levels

SRL	Name	Definition	Value Min	Value Max
1	Concept Refinement	Refine initial concept. Develop system/technology development strategy	0,1	0,39
2	Technology Development	Reduce technology risk and determine appropriate set of technologies to integrate into a full system	0,4	0,59
3	System Development and Demonstration	Develop a system or increment of capability; reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for producibility; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety, and utility	0,6	0,79
4	Production and Development	Achieve operational capability that satisfies mission needs	0,8	0,89
5	Operations and Support	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manor over its life cycle	0,9	1

5.2 Initial assessment of readiness of the component and platform

At this stage we conducted a first assessment of the readiness of the different components of the platform. This preliminary assessment provides a first view on the TRL, IRL and SRL of the InCUBE platform that will serve as a baseline reference to evaluate the progress of the platform integration.

5.2.1 Initial evaluation of Technology Readiness Levels

The following table present the evaluation of the initial technology level of the different components of the InCUBE platform.

Table 10 - InCUBE platform components initial TRL

Partners	Asset	Initial TRL
CERTH	Digital Building Logbook	5
CIRCE	Modular BIM/CIM Platform	6
KENT	Eclipse sensiNact	6
CERTH	INTEMA	7
CERTH	VERIFY	7
CERTH	InCUBE planning guide P-GUIDE	6
RINA-C	Resilience Dashboard	6
CERTH	AR/VR Training Suite	7
CIRCE	Lean Construction Platform	5
CERTH	Job Scheduling Optimizer	5
CERTH	Renovation Marketplace	7
METRO7	IPD, A3 and LPS-driven Rehabilitation	6
CIRCE	Energy Cloud EMS	6
TERA/FBK	Smart Building EMS S-BEMS	5
EVOLVERE/FBK	Distric EMS (EvoDistrict)	7
RINA-C	PPE Monitoring System	6
RINA-C	Anti-Collision System (ACS)	6
RINA-C	Area Boundary (AB) System	6
FBK	Terrestrial laser scanning (TLS), inspection and 3D modelling	6
VW	Drone-enabled Scan-to-BIM 3D modelling	7
METRO7	Laser 3D Scanning	6
VW	BIM-based Design of Prefab Modules	5
KOVER	Modular Facades with Integrated Building Elements	6
K-FLEX	K-ROCK CNX insulation material	4
WEBO / VW	BIPV pre-installed on Prefab Facades	5
ABORA	Hybrid Thermal Solar Panels (BI-SHE)	7
TEGOLA	Tegosolar® BIPV Shingles	6

Partners	Asset	Initial TRL
VW	BIM-Connected robotic systems	6
VW	Construction Waste Sorting Robot	5
RINA-C	Waste Tracking and Management	6
RINA-C	Environmental Monitoring System	7
Trento/FBK/ENEREN	Smart Borehole Thermal Energy Storage BTES	6
ENEREN	Low GWP DHC connected GSHP	6
Trento/FBK/ENEREN	Low Temperature 100% RES DHC	6

5.2.2 Initial evaluation of Integration and System Readiness Levels

The following matrix presents the evaluation of the initial integration readiness levels of the different components. It is based on the architecture defined in section 4, identifying the necessary integrations between the different components. It focuses only on components that are relevant in term of integration (i.e., that require the set-up of actual interoperability beyond a simple unique importation of data from one component to another).

Table 11 - Initial Integration Readiness Level of InCUBE platform components

Partners	Asset	Digital Building Logbook	Modular BIM/CIM Platform	Eclipse sensiNact	INTEMA	VERIFY	InCUBE planning guide P-GUIDE	Resilience Dashboard	AR/VR Training Suite	Lean Construction Platform	Job Scheduling Optimizer	Renovation Marketplace	Energy Cloud EMS	Smart Building EMS S-BEMS	Distric EMS (EvoDistrict)	PPE Monitoring System	Anti-Collision System (ACS)	Area Boundary (AB) System	Waste Tracking and Management	Environmental Monitoring System
CERTH	Digital Building Logbook	9		1	1	1	1	1	1		1	1								
CIRCE	Modular BIM/CIM Platform		9	1	1		1	1	1	1		1	1	1						
KENT	Eclipse sensiNact	1	1	9				1		1	1			1						
CERTH	INTEMA	1	1		9	1														
CERTH	VERIFY	1			1	9	1			1	1									
CERTH	InCUBE planning guide P-GUIDE	1	1			1	9			1	1									
RINA-C	Resilience Dashboard	1	1	1				9	1	1	1					1	1	1	1	1
CERTH	AR/VR Training Suite	1	1					1	9			1								
CIRCE	Lean Construction Platform		1	1		1	1	1		9	1									
CERTH	Job Scheduling Optimizer	1		1		1	1	1		1	9									
CERTH	Renovation Marketplace	1	1						1			9								
TERA/FBK	Energy Cloud EMS		1										9							
EVOLVERE/F	Smart Building EMS S-BEMS		1	1										9	1					
RINA-C	Distric EMS (EvoDistrict)													1	9					
RINA-C	PPE Monitoring System							1								9				
RINA-C	Anti-Collision System (ACS)							1									9			
FBK	Area Boundary (AB) System							1										9		
VW	Waste Tracking and Management							1											9	
RINA-C	Environmental Monitoring System							1												9

Following the System Readiness Level methodology, we calculated an initial SRL of 0.253 for the InCUBE platform. This correspond to the "Concept Refinement" phase which is normal for a project at this stage.

SRL	Name	Definition	Value Min	Value Max
1	Concept Refinement	Refine initial concept. Develop system/technology development strategy	0,1	0,39
2	Technology Development	Reduce technology risk and determine appropriate set of technologies to integrate into a full system	0,4	0,59
3	System Development and Demonstration	Develop a system or increment of capability; reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for producibility; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility	0,6	0,79
4	Production and Development	Achieve operational capability that satisfies mission needs	0,8	0,89
5	Operations and Support	Execute a support porgram that meets operational support performance requirements and sustains the system in the most cost effective manor over its life cycle	0,9	1

Figure 9 - Initial evaluation of InCUBE platform System Readiness Level

We will monitor the progress of the project on this scale throughout the project activities.

6 Conclusion

This document has presented an initial perspective on the architecture of the InCUBE digital platform. The current perspective will be used as a reference for the integration work of WP3 and WP5.

Yet this initial perspective is only a preliminary step toward the set-up of the final architecture of the InCUBE platform. The initial integration and development efforts of WP3 and WP5 will put this architecture to the test and provide critical feedback on its integration model. The set-up of the initial interoperability framework, resulting from the work of task 3.1 (by project month 20) will provide a first set of feedback that will result in a necessary update and upgrade of the current architecture. This will coincide with the release of deliverable D1.9, which will update the current version of this document.

In parallel, the work of WP7 will help clarify the requirements of the project pilots and the specific use cases linked with the digital platform. This will also bring necessary amendments to the architecture, as specific needs of the different use case and the involved stakeholders may require adjustments in the architecture and the interactions of the different components.

A second iteration will then provide additional feedback after month 36. This will take into account both feedback from the work of the other tasks and, more importantly, field feedback from the early deployments of the project pilots.

This deliverable has also established the methodology for following the progress of the project integration with the definition of the TRL, IRL, and SRL scales and a first evaluation of the readiness of the components and platform. This will serve as a baseline for future evaluation, enabling precise tracking of project progress toward an integrated platform. This work will be taken up and continued through the work of WP3 (as a basis for interoperability evaluation), but also through the work of WP9 on the exploitation strategy. Indeed, the evaluation of the technology, integration, and system readiness provides an important perspective to evaluate the potential exploitation strategy of the different components and of the platform as a whole.

Overall, this document presents an important milestone for the InCUBE project, enabling the start of multiple activities and providing a baseline and reference for the architecture and integration of digital components.

7 Annex

7.1 Use Case Template

ID: DemoSiteName_UseCaseShortName
Title:
Use Case short description and rationale
Example: A dwelling occupant wants to compare its electricity consumption to the other dwellings, …
Main Actors (initiators of the Use Case), their benefits and roles
Example: Dwelling occupant, …
Secondary Actors (participating in the Use Case), their roles
Example: Dwelling owner
Business Goal
Example: Increase energy consumption efficiency by letting the occupant detect non-optimal energy usage, …
Preconditions
Example: Energy consumption measurements must be available at dwelling level, …
Detailed Scenario and main supporting blocks
Example: detailed scenario in text & visual diagrams

Postconditions
Example: expected state after the Use Case
User Requirements
Example: User should be able to have an overview of the energy consumption of its dwelling, …
Derived System Requirements
Example: ***Functional requirements:*** *The system shall keep a history of energy consumption.* *The system shall have a security module to let a user see only what it is authorized to.* *…* ***Non-functional requirements:*** *…*
Constraints and Barriers (technical, regulatory, …)
Example: Privacy issues, …
Relevant InCUBE Components involved
Example: Logbook, Modular BIM/CIM Platform, Smart Energy Manager, …
How will this use case be demonstrated?
Example: Field trial, integration test environment, …

7.2 Component description template

Owner	Component group
(Short name)	(R-GUIDE, Digital Twin, …)

<Description of the component, as in the grant agreement or in deliverable 10.2>

Input

<List of inputs for that component: the component actively reads those inputs. A list of protocols can be given along the input formats>

Input origin	Access description	Input Format

Read access from components

<List of components that will read/pull/poll data from this component. The access protocols and formats must be described>

Client component	Access description	Access protocol

Write access to components

<List of components that will write/push data to this component. The access protocols and formats must be described>

Target component	Access description	Access protocol