Deliverable: D5.4
Version: 1.0
Due date: 31/03/2023
Submission date: 12/04/2023
Dissem. lvl: Public

Ref. Ares(2023)2597917 - 12/04/2023

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H2020-NMBP-ST-IND-2018-2020- GA 958218

PLUG-AND-USE RENOVATION WITH ADAPTABLE LIGHTWEIGHT SYSTEMS

D5.4 Methodology and guidelines

for LYSIS-MODEST deployment

Version: 1.0

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Distribution list

External		Internal	
European Commission	1x	Consortium partners	1x

Change log

Issue	Date	Pages	Remark / changes	Pages
0.1	07.12.2022	7	Initial TOC prepared	All
0.2	07.01.2023	15	Input by ITeC incorporated	7-14
0.3	07.04.2023	34	First complete issue by INTRA	All
0.4	10.04.2023	34	WP leader review by INTRA	All
1.0	12.04.2023	34	Reviewed and edited by PC	All

To be cited as

INTRA (2022): "D5.4 – Methodology and guidelines for LYSIS-MODEST deployment" of the HORIZON 2020 project PLURAL. EC Grant Agreement No. 958218, Luxemburg, Country.

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Terms, definitions, and abbreviated terms

API	**A**pplication **P**rogramming **I**nterface
BEDEC	**B**ase de dades **E**structarada **d'e**lements **C**onstructius (Structured Database for Construction Elements in Catalan)
BIM	**B**uilding **I**nformation **M**odelling
CI/CD	**C**ontinuous **I**ntegration / **C**ontinuous **D**evelopment
CPU	**C**entral **P**rocessing **U**nit
DST	**D**ecision Support Tool
EPD	**E**nvironmental **P**roduct **D**eclaration
GA	**G**rant **A**greement
GUI	**G**raphical **U**ser **I**nterface
HTTP	**H**yper**t**ext **T**ransfer **P**rotocol
HTTPS	**H**yper**t**ext **T**ransfer **P**rotocol **S**ecure
IFC	**I**ndustry **F**oundation **C**lasses
KPI	**K**ey **P**erformance **I**ndicator
LCA	**L**ife **C**ycle **A**ssessment
LCC	**L**ife **C**ycle **C**osting
MODEST	**M**ulti-**O**bjective **DE**cision **S**upport **T**ool
nZEB	**n**early **Z**ero **E**nergy **B**uilding

OS   **O**perating **S**ystem

PnU   **P**lug and **U**se

REST   **RE**presentational **S**tate **T**ransfer

SaaS   **S**oftware **as a S**ervice

SEM   **S**mart **E**nergy **M**anagement

SSL   **S**ecure **S**ockets **L**ayer

TCP   **T**ransmission **C**ontrol **P**rotocol

TCQ   **T**ime **C**ost and **Q**uality

TLS   **T**ransport **L**ayer **S**ecurity

TSDB   **T**ime **S**eries **D**ata**B**ase

UI   **U**ser **I**nterface

URL   **U**niform **R**esource **L**ocator

VM   **V**irtual **M**achine

WP   **W**ork **P**ackage

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Executive summary

The present document describes the work done in the frame of:

- T5.7 "Methodology for deployment of LYSIS-MODEST to the six pilots"
- T5.5 "Pilot deep retrofit methodology and planning"

The deployment strategies followed in each pilot, which showcase the flexibility and extensibility of the LYSIS-MODEST platform, have already been described in detail in "D5.2 – Multi-objective and multi-criteria Decision Support Tool (MODEST)". To avoid replication of the same information, here the focus is on the core components of the LYSIS-MODEST platform that enable this kind of flexibility.

Deliverable D5.4 provides the specifications of the required computing infrastructure that can host the core LYSIS-MODEST components and discusses its setup so that is conforms to high security and performance standards. The deployment methodology of the individual components is then presented in detail providing guidelines regarding their placement, configuration and interactions. Next, the TCQ deep retrofit methodology is presented and the process followed for its integration to the LYSIS-MODEST is described. In addition, some changes on the TCQ-derived KPIs are discussed, followed by the values of the calculated KPIs. In the end, we present our conclusions related to both developed methodologies.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958218

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1. Introduction

Deliverable *"D5.4 – Methodology and guidelines for LYSIS-MODEST deployment"* is a report providing (i) guidelines for the use and implementation of the combined LYSIS-MODEST platform (developed by INTRA) and (ii) a description of the TCQ methodology (developed by ITeC) and its application in the PLURAL project. In particular, here we present the outcomes of the following two tasks:

- T5.7 "Methodology for deployment of LYSIS-MODEST to the six pilots"
- T5.5 "Pilot deep retrofit methodology and planning"

Originally, according to the GA, this deliverable was linked just with T5.7, but based on the updated implementation plan of the WPs, it was decided to also incorporate the results of task T5.5.

The LYSIS-MODEST platform consists of several different subsystems, including a Persistent Messaging and Storage System (StreamHandler), a Time Series Database (InfluxDB), Monitoring Data Adapters, KPI Importers, KPI Calculators, UI & Monitoring Tools and last but not least, MODEST DST (Decision Support Tool). All these subsystems have different characteristics in terms of hardware requirements, networking needs, security features, etc.

The main objective of T5.7 was the creation of a deployment methodology that would allow the flexible installation and configuration of the LYSIS-MODEST platform. Towards this objective, two goals were defined:

i. Specify a configuration for the supporting computing infrastructure that would facilitate the seamless, smooth and secure operation of the platform.

ii. Provide detailed descriptions of the deployment steps emphasizing on the flexibility offered by the followed approach.

The main objective of T5.5 was the creation of a methodology to obtain more information for the PnU kits (e.g., environmental impacts, prices, dimensions, etc.) by applying ITeC's methodology which is based on databases and BIM libraries. To achieve this objective, two goals were defined:

i. Design a methodology to integrate the LYSIS-MODEST with the TCQ system. This would allow users using the PLURAL tools will be able to also use ITeC's tools in an easy way.

ii. Calculate LCA-related KPIs that could then be extracted from ITeC's software without third party information (e.g., manufacturer data) and added to the LYSIS-MODEST platform.

Based on the above objectives, the rest of the deliverable in structured as follows:

- Section 2 presents the deployment methodology of the LYSIS-MODEST platform including the setup of the required infrastructure and the installation of all the core software components.
- Section 3 focuses of the TCQ methodology, its integration with the LYSIS-MODEST platform and the results of the calculated KPIs.
- Section 4 summarizes the results of both methodologies.

2. Deployment of LYSIS-MODEST platform

This section provides guidelines for the deployment and setup of the core LYSIS-MODEST components. In particular, the LYSIS-MODEST consists of the following main components:

- Persistent Messaging and Storage System (StreamHandler)
- UI & Monitoring (AKHQ, etc.)
- Time Series Database (InfluxDB)
- Data Adapters and KPI Importers (for integrating monitoring and simulated data)
- MODEST (backend and frontend)
- CI/CD stack (Jenkins, JFrog Registry, Portainer)

Next, section 2.1 describes the acquisition and proper setup of the required computing infrastructure, and section 2.2 presents the deployment and configuration of the various software components.

2.1 LYSIS infrastructure setup

To tackle the hosting requirements of the LYSIS-MODEST platform there is a need for a set of servers. For the purposes of the PLURAL project multiple *virtual* servers have been acquired from a public cloud provider, namely Hetzner Cloud [1], under direct contract with INTRA. It is also possible to proceed to an on-premises installation using servers with similar characteristics, however the cloud offers many advantages, such as automated periodic backups, flexibility in scaling up or down depending on the current needs, higher level of security and automatic compliancy to regulatory frameworks. Note that the selected Hetzner servers are located in the European Union, and Hetzner offers a Data Processing Agreement (DPA) [2] [3] that in case of processing personal data can verify compliance with the General Data Protection Regulation (GDPR). Alternatively, any other cloud provider with similar offerings can be chosen.

Table 1 lists the virtual machines (VMs) that make up the LYSIS infrastructure. Based on the current project needs, the infrastructure consists of 17 VMs distributed as follows:

- 12 are used to support and enhance the functionality of the Persistent Messaging and Storage System, which is the StreamHandler. These include three clusters of servers for Apache Kafka Brokers [4], Apache ZooKeeper nodes [5] and Apache Kafka Connect [6]. To ensure high-availability, replication and fault-tolerance each of these clusters consists of three servers, which could grow up to five if it is needed to ensure that the quorum is always set even during system upgrades. There are also servers for hosting the REST Proxy

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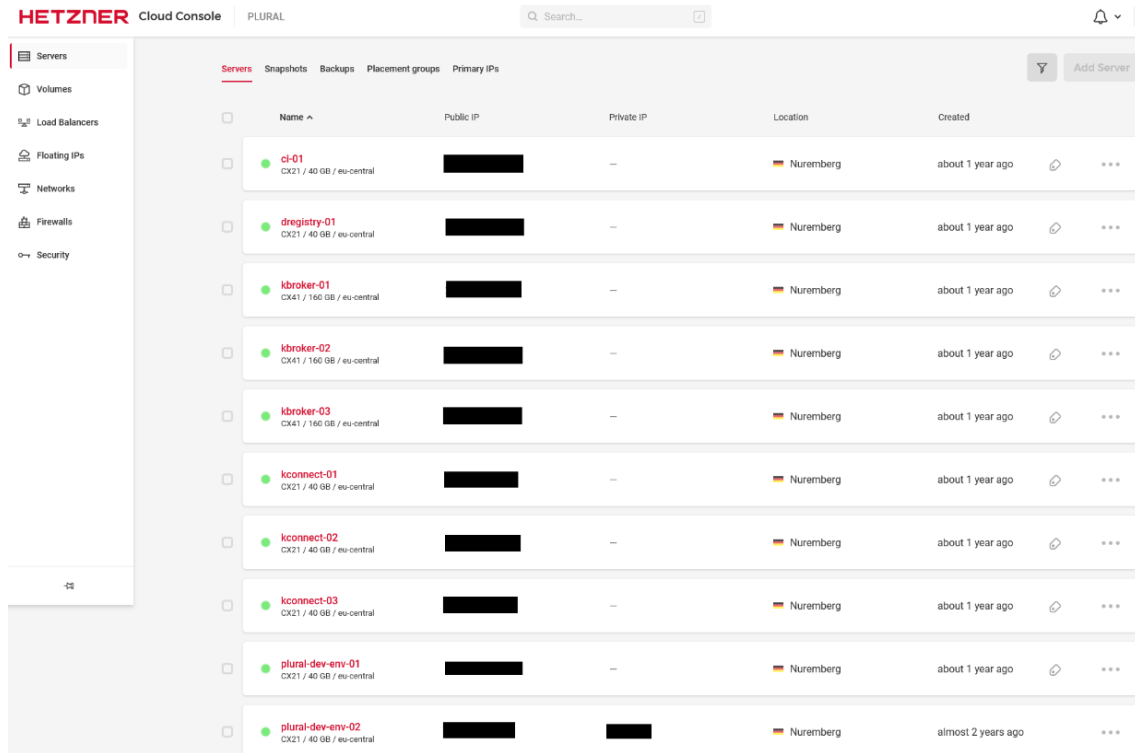Submission date: 12/04/2023
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[7], which makes the Apache Kafka cluster accessible via a RESTful API, the Schema Registry [8], which keeps the schemas of the message data, and UI & Monitoring tools, such as AKHQ [9].

- Three are used for the deployment and testing of the various accompanying software components, such the Time Series Database, which is the InfluxDB [10], the developed Data Adapters, KPI Importers & Calculators and the MODEST tool along its single sign-on utility (Keycloak [11]).
- Two are used for the CI/CD stack including supporting tools like Jenkins [12], Portainer [13] the JFrog Container Registry [14].
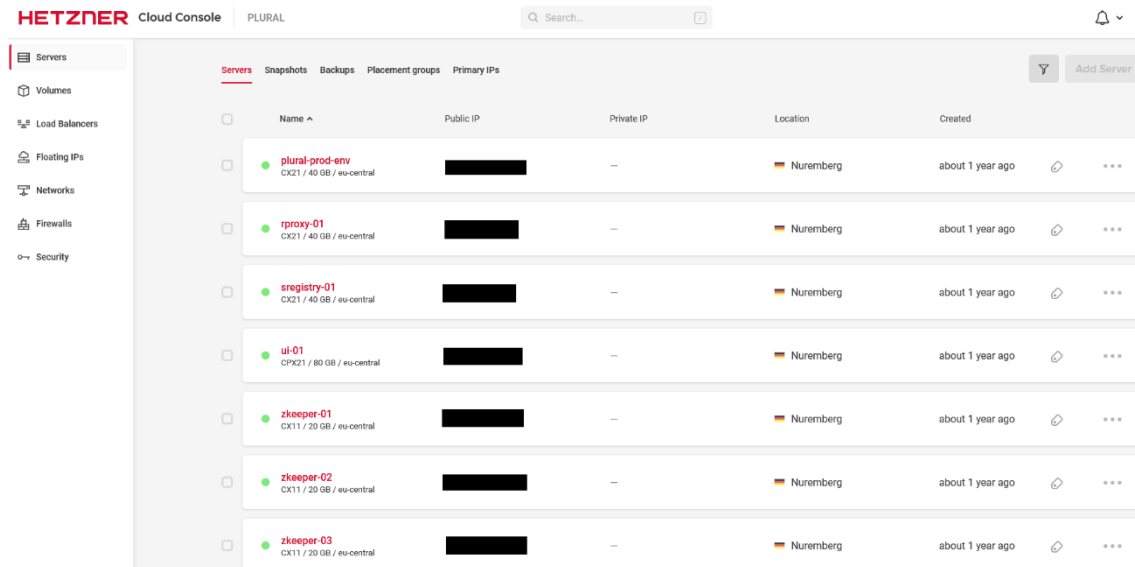
TABLE 1: LYSIS INFRASTRUCTURE SERVERS

Server type	Server name(s)	Hetzner vServer type	vCPU	RAM (GB)	Disk space (GB)
Apache Kafka Broker (x3)	kbroker-01 kbroker-02 kbroker-03	CX41	4	16	160
Apache ZooKeeper (x3)	zkeeper-01 zkeeper-02 zkeeper-03	CX11	1	2	20
Apache Kafka Connect (x3)	kconnect-01 kconnect-02 kconnect-03	CX21	2	4	40
REST Proxy	rproxy-01	CX21	2	4	40
Schema Registry	sregistry-01	CX21	2	4	40
UI & Monitoring	ui-01	CPX21	3	4	80
Software Deployment (x3)	plural-dev-env-01 plural-dev-env-02 plural-prod-env	CX21	2	4	40
CI/CD Tools	ci-01	CX21	2	4	40
Container Registry	dregistry-01	CX21	2	4	40

Table 1 also includes the hardware characteristics of the VMs in terms of CPU, memory and storage. In particular, depending on the intended functionality, four different types of Hetzner vServers are used: CX41 [15], CX21 [16], CPX21 [17] and CX11 [18]. Figure 1 and Figure 2 present screenshots from Hetzner's Cloud Console UI showing how the acquired infrastructure should look like. Note that depending on the application domain and the amount of incoming data, more advanced versions of the vServers may be needed.

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FIGURE 1: LYSIS INFRASTRUCTURE VMS FROM HETZNER CLOUD – PART 1

FIGURE 2: LYSIS INFRASTRUCTURE VMS FROM HETZNER CLOUD – PART 2

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In terms of operating system, the Rocky Linux [19] open-source enterprise operating system (version 8) is the preferred OS that is installed in all VMs as it offers stability, customization and strong community support.

During the OS installation process the following security measures should take place:

- Setup of strong admin password with at least 15 characters, numbers, symbols, uppercase letters and lowercase letters.
- Full disk encryption using LVM (Logical Volume Management) [20] for disk management and LUKS (Linux Unified Key Setup) [21] encryption.

After the OS installation, it is advised that the password-based access to the VMs for management purposes is disabled, and only SSH-key based authenticated access is allowed using cryptographic keys [22]. In addition, to prevent the most common network attacks, firewall protection of the infrastructure servers is mandatory in order to drop all incoming, outgoing and forwarded packets and allow only specific connections. This can be achieved in two ways: either by using the netfilter framework [23] and setting the proper iptables rules, or by using the firewalling functionality [24] integrated in the Hetzner's Cloud Console UI to control the inbound/outbound traffic.

2.2   Deployment of the LYSIS-MODEST components

Once the infrastructure is properly set up, the actual deployment and the configuration of the various software components can take place. Figure 3 presents the deployment diagram that models the physical architecture of the LYSIS-MODEST platform, showing the relationships between the hardware (VMs/servers) and the software components. All devices (VMs/servers) are Docker-enabled, meaning that they can host and manage containers, and their different colour coding is representative of the functionality provided by the hosted components. This is categorised in three groups:

- Persistent Messaging and Storage System
- Developed & Third-Party Software
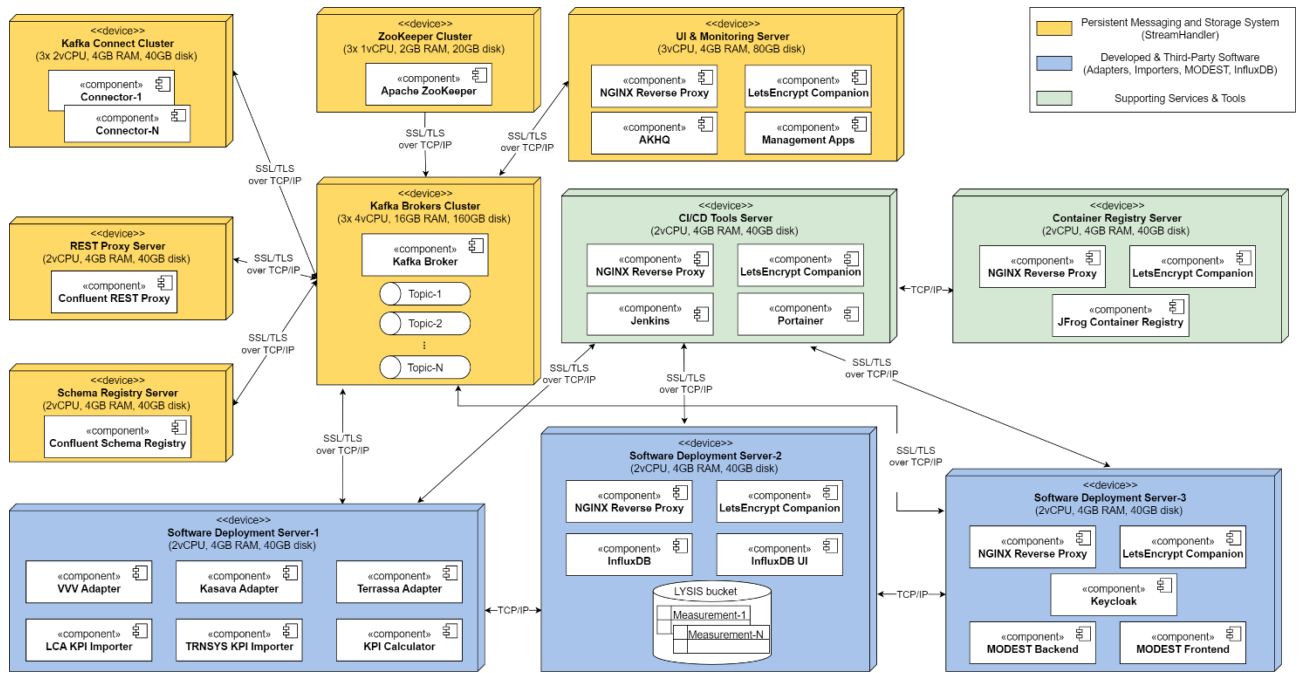- Supporting Services and Tools

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FIGURE 3: DEPLOYMENT DIAGRAM OF LYSIS-MODEST

The **Persistent Messaging and Storage System** (yellow-coloured devices) is the StreamHandler, which here consists of a highly available and secure deployment of the Apache Kafka message bus.

- The core of the system is the *Kafka Brokers Cluster* that forms the storage layer, storing the data streams in a distributed, durable and fault-tolerant manner. In this cluster is where the LYSIS messages/records are stored in topics and partitions.
- The *ZooKeeper Cluster* handles the leadership election of the Kafka Brokers and provides a centralized suite of services that enable configuration, synchronization and service discovery activities (naming registry).
- The *Kafka Connect Cluster* can be used for the deployment of so-called Connectors, which are used for the streaming of data inside the Kafka Brokers Cluster, in distributed mode, providing scalability and automatic fault tolerance.
- The *REST Proxy Server* enables the access to the Kafka Brokers Cluster for producing/consuming messages and performing monitoring/administrative actions via a RESTful interface.
- The *Schema Registry Server* provides a centralized repository for managing and validating schemas for topic message data, and for serialization and deserialization of the data over the network.

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- The *UI & Monitoring Server* includes the AKHQ for managing and viewing the data inside the Kafka Brokers Cluster along with other management-related software.

All servers must have installed firewalls enabling input/output interactions only with specific other servers and communicate with each other using SSL/TLS over TCP/IP. The topics currently used, their configuration and the schemas are described in detail in "D5.2 – Multi-objective and multi-criteria Decision Support Tool (MODEST)" (Section 4, Appendix A, B and C) and the accompanying Annexes. Installation instructions for the various components can be found in [25], [26], [27] and [28].

The **Developed & Third-Party Software** (blue-coloured devices) includes any additional third-party software deployed to support the provided functionality, as well as the components developed by the INTRA team during the PLURAL project. This functionality is distributed in the following three servers.

Software Deployment Server-2 is hosting InfluxDB, the Time Series database for the storage of the demo site monitoring data, along its UI that enables the building of custom dashboards to visualize the data and perform administrative operations. In this server the LYSIS bucket and the related measurements are stored. The measurements currently used, their fields and tags are described in detail in "D5.2 – Multi-objective and multi-criteria Decision Support Tool (MODEST)" (Appendix A, B and C) and the accompanying Annexes. Installation instructions can be found in [29].

Software Deployment Server-1 is used for deployment of the developed Data Adapters and the KPI Importers components. More specifically, it includes the Python modules for integrating PLURAL monitoring data from the VVV (Greek) demo site (https://github.com/plural-eu/adapter-vvv), the Kasava (Czech) demo site (https://github.com/plural-eu/adapter-kasava) and the Terrassa (Spanish) demo site (https://github.com/plural-eu/adapter-terrassa). These adapters are responsible for retrieving the various demo site-specific quantities and sending them both to Apache Kafka topics and to InfluxDB measurements. The usage of different protocols and deployment strategies for each demo site indicate the flexibility of the used LYSIS-MODEST methodology.

The same server hosts the KPI Importer modules (https://github.com/plural-eu/kpi-calculator) that integrate KPIs coming from TCQ's LCA analysis (performed by ITeC, see also section 3) and from TRNSYS simulations (performed by the simulation partners IREC/SPF). These KPIs are received in spreadsheets following a pre-specified format and are sent both to Apache Kafka

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topics and to InfluxDB measurements. In addition, the server includes components calculating KPIs related to demo site monitoring data.

Software Deployment Server-3 is used for the MODEST tool including both its backend (https://github.com/plural-eu/modest-backend) and its frontend/UI (https://github.com/plural-eu/ui-modest-lysis). The MODEST Backend retrieves data from Apache Kafka topics and InfluxDB measurements, while the MODEST Frontend (https://modest.plural.rid-intrasoft.eu/) also perform InfluxDB queries using the Flux language. The server also hosts the Keycloak instance that provides single sign-on with identity and access management functionality for the MODEST Frontend. Keycloak installation instructions can be found in [30].

The **Supporting Services and Tools** (green-coloured devices) provides the tools belonging to the CI/CD stack. In particular, there is a CI/CD Tools Servers that hosts the Jenkins automation server (https://jenkins.plural.rid-intrasoft.eu/) and the Portainer containers management tool (https://portainer.plural.rid-intrasoft.eu/) and communicates with all the above mentioned Software Deployment Servers. Furthermore, a separate server is used for the JFrog Container Registry (https://registry.plural.rid-intrasoft.eu/) where the produced Docker container images are stored. Installation instructions for these tools can be found in [31], [32] and [33].

Note that all services and tools that are exposed to the outside world (AKHQ, InfluxDB UI, Jenkins, Portainer, JFrog Container Registry, MODEST-LYSIS UI) are being accessed through a reverse proxy configuration using the NGINX web server [34]. The used configuration includes a companion container that handles the automated creation, renewal and use of Let's Encrypt [35] SSL/TLS certificates for the proxied containers. For more information see: https://github.com/nginx-proxy/acme-companion.

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3. TCQ deep retrofit methodology

This section presents the activities that took place during the course of T5.5 "Pilot deep retrofit methodology and planning". In particular, section 3.1 gives an overview of the existing TCQ methodology and section 3.2 presents the design of the new methodology, which integrates the TCQ methodology with the LYSIS-MODEST of the PLURAL solution, based on ITeC's experience and considering more contributions from other ways of developing projects, regulations, etc. Then, section 3.3 showcases the actual application of ITeC's deep retrofit methodology in the PLURAL project and section 3.4 presents the calculated KPIs.

3.1 Methodology overview

The TCQ (Time, Cost, and Quality) methodology belongs to ITeC as part of its Integrated Project Monitoring Methodology. It is based on:

- Two linked software modules: TCQ (desktop version) and TCQi (cloud SaaS version) [36]
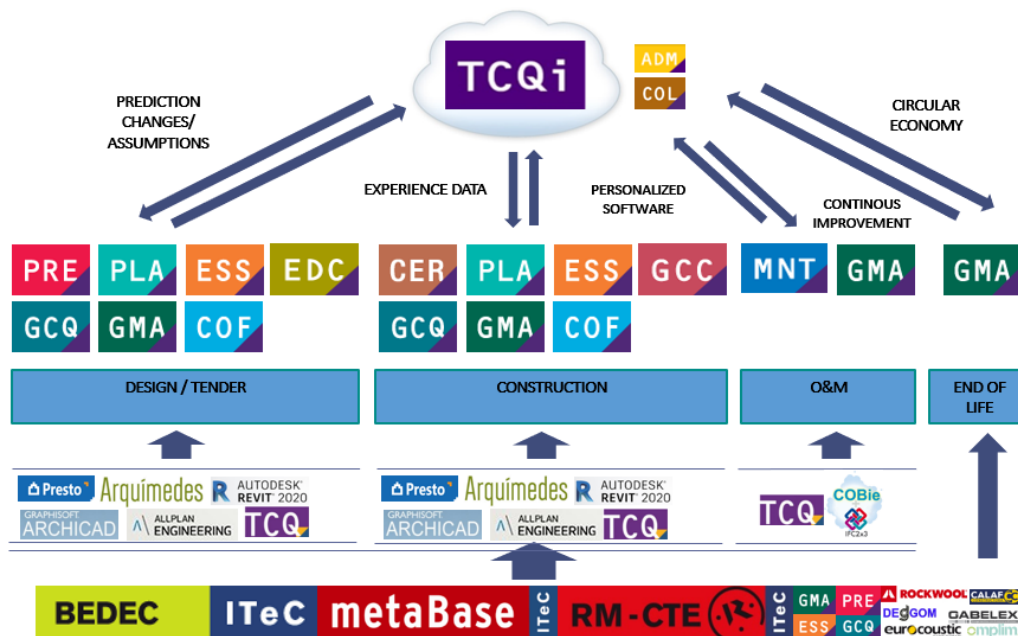- The Construction Elements Database (BEDEC) [37] with more than 800.000 construction elements

FIGURE 4: TCQ/TCQI METHODOLOGY OVERVIEW

Figure 4 depicts the methodology and the high-level interactions between the various modules. As it can be seen, the methodology covers all life cycle phases of a project:

i. design statement
ii. detailed design
iii. bid-tender design
iv. design variation
v. operation & maintenance, and
vi. end of life stage.

In addition, the methodology includes BIM utilities in the modules for budgeting (PRE), monthly payment (CER) and construction programme and scheduling (PLA). The combination of these BIM utilities with the construction element database (BEDEC) links all the phases of a project's life cycle with each other.

The TCQ software framework utilizes several modules to obtain the information requested by the user. Some of the modules that can be used in the methodology designed for the PLURAL solution are the following:

- PRE: Budget and technical conditions
- CER: Certifications and economic monitoring (and built of quantities)
- PLA: Time planning and monitoring
- ESS: Health & safety studies and plans
- GCQ: Quality control management
- GMA: Environmental model management

Note that GMA, in particular, is used to calculate the KPIs related to the LCA that are presented in section 3.4.

3.2 Integration of TCQ methodology with LYSIS-MODEST

Figure 5 presents in a graphical way the methodology that was designed to integrate the TCQ framework with the LYSIS-MODEST tools.
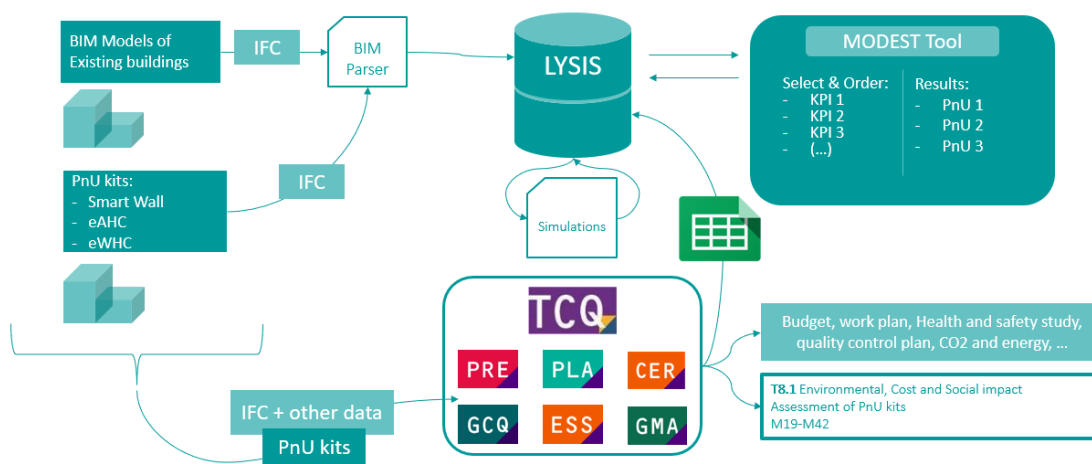
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FIGURE 5: INTEGRATION OF TCQ WITH LYSIS-MODEST

The workflow starts with two different types of digitals models: (a) existing buildings and (b) the PnU kits objects modelled in previous tasks (T5.1). Both types of models are exported in IFC files and sent to the BIM Parser tool to obtain the parameters required for the energy simulations. The IFC files are retrieved via the messaging and storage system provided by the LYSIS platform and the produced parameters/metadata are also transferred in the LYSIS infrastructure via the same messaging mechanism.

In the following, these data can be retrieved by the simulation partners and used in their simulations for testing various scenarios combining different configuration parameters. The simulation results are also collected and stored in the storage mechanisms provided by the LYSIS platform from where the user can access them through the UI provided by the MODEST tool. In particular, the user can perform several actions, such as selecting, filtering and ordering KPIs, to obtain the best PnU kit configuration.

In parallel, another series of interactions take, shown in the lower part of Figure 5. The IFC files of the digital models are processed and transformed into a TCQ-compatible format so that they can be used and manipulated by the TCQ software. With the data imported into TCQ, the different modules can be used to obtain the budget, create the work plan, perform the economic monitoring, perform the quality control plan, perform the health and safety plan, calculate the CO_2 emissions and energy consumptions in the first phases of the project, among others. In a next step, the produced results are exported in a spreadsheet following a pre-specified format and are finally being imported in the LYSIS's messaging and storage system. From there, they can be

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accessed by the users via the MODEST UI. Note that other outputs obtained with this methodology will be used by T8.1 "Environmental, Cost and Social Impact Assessment of PnU kits".

Through the two above mentioned data flows, the TCQ methodology is combined with the LYSIS-MODEST platform and applied to the PnU kits of the PLURAL solutions.

3.3 Application of the integrated methodology

Figure 6 depicts the actual workflow of the integrated TCQ and LYSIS-MODEST solution as it is applied in the PLURAL project.
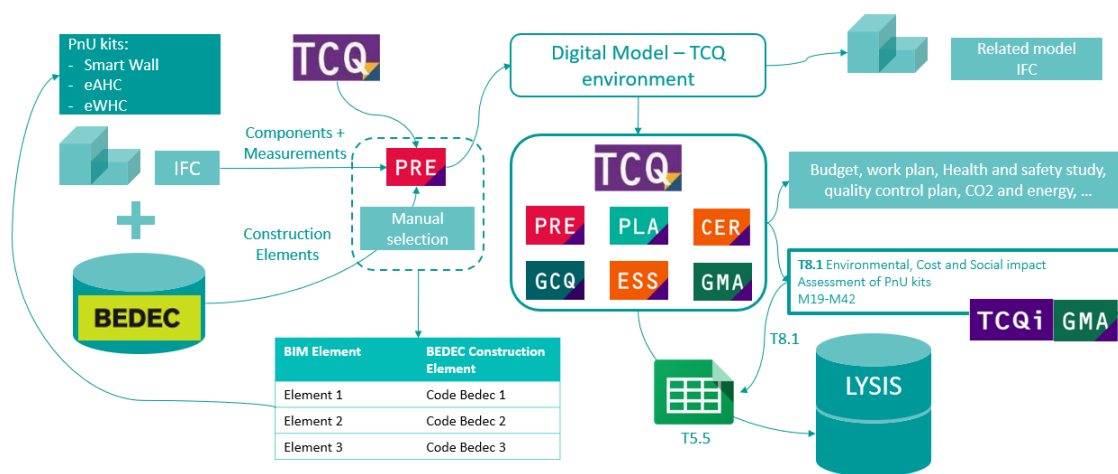

FIGURE 6: WORKFLOW OF THE INTEGRATED TCQ AND LYSIS-MODEST SOLUTION

As it can be seen at the left side of the figure, the available data sources are two. On the one hand, there are data in IFC-formatted files providing information on the PnU kits and their various measurements. On the other hand, the Construction Elements Database (BEDEC) contains information about the constructions elements regarding with the costs, documents, environmental indicators, and so on.

Data from both data sources can be combined and linked together by manually selecting project components and their associated construction elements. This way a digital model based on the project budget is created for the TCQ ecosystem. This procedure is manual the first time and generates a table where the components of the PnU Kits are associated with the BEDEC elements. Figure 7 shows an example of such a manual creation of relationship between an IFC file and BEDEC's construction elements.
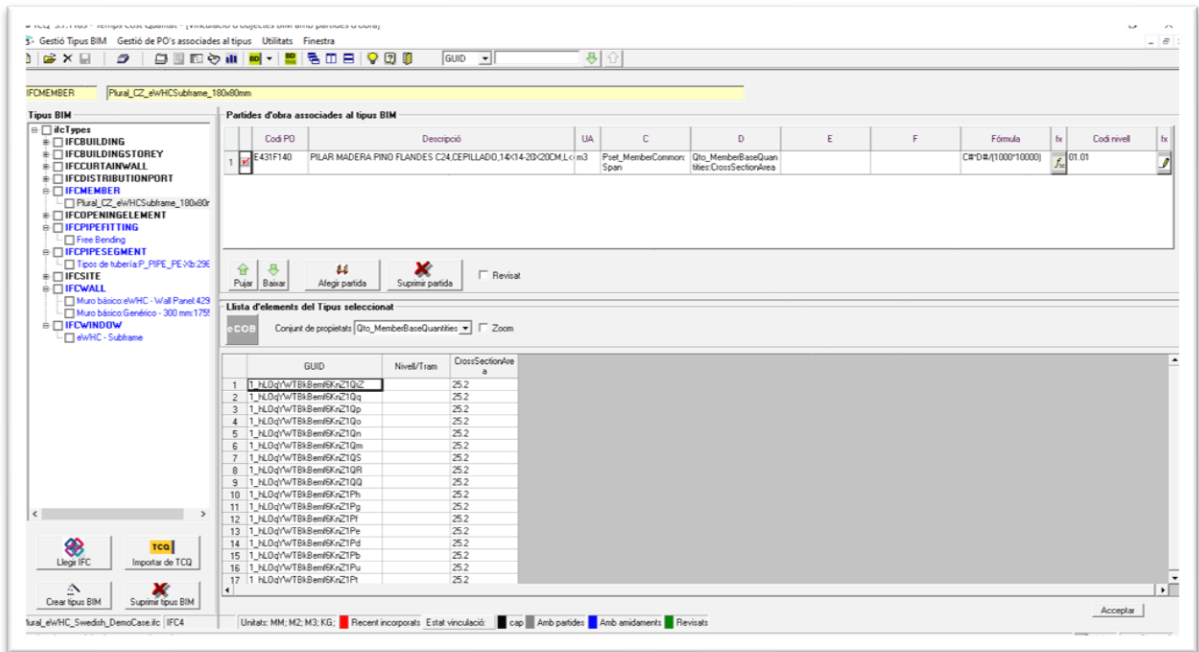
FIGURE 7: EXAMPLE OF SELECTION RELATIONSHIP BETWEEN IFC FILES AND BEDEC

The described process has two main advantages:

- It is possible for the user to visualize the elements in a BIM viewer while working.
- The user (or any other interested party) can use the created relationship for future projects.

The following series of screenshots (Figure 8-Figure 13) present how the different PnU kits for the real and virtual demo sites are shown with a BIM viewer on the right side and the created TCQ digital model on the left side.
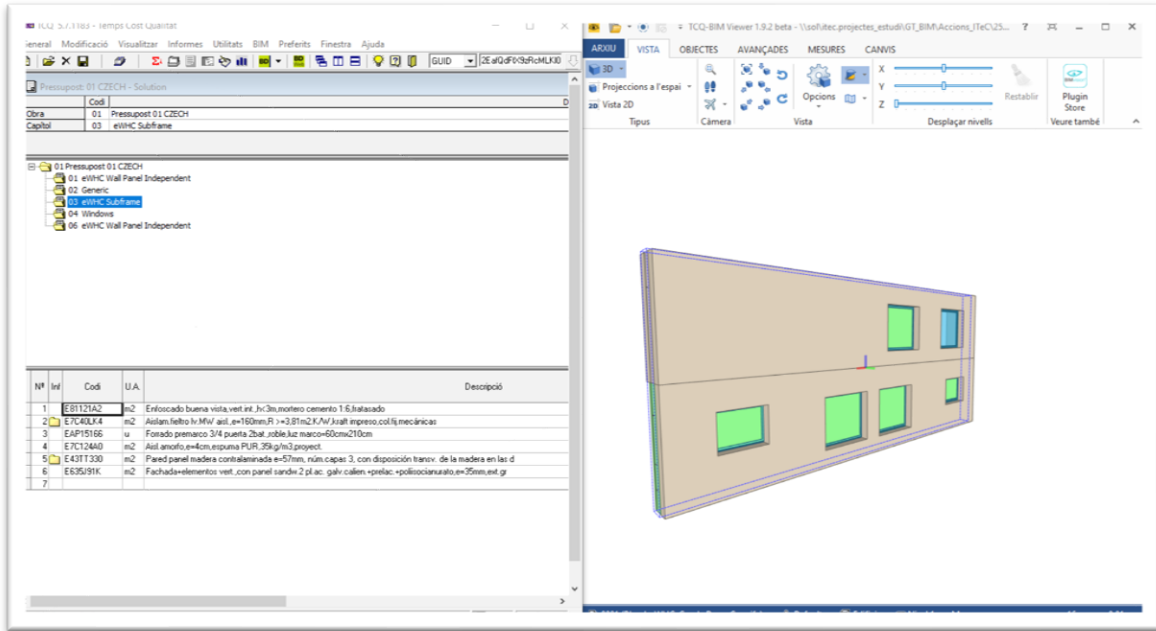
FIGURE 8. VISUALIZATION OF PNU KITS FOR THE CZECH DEMO CASE (KASAVA)
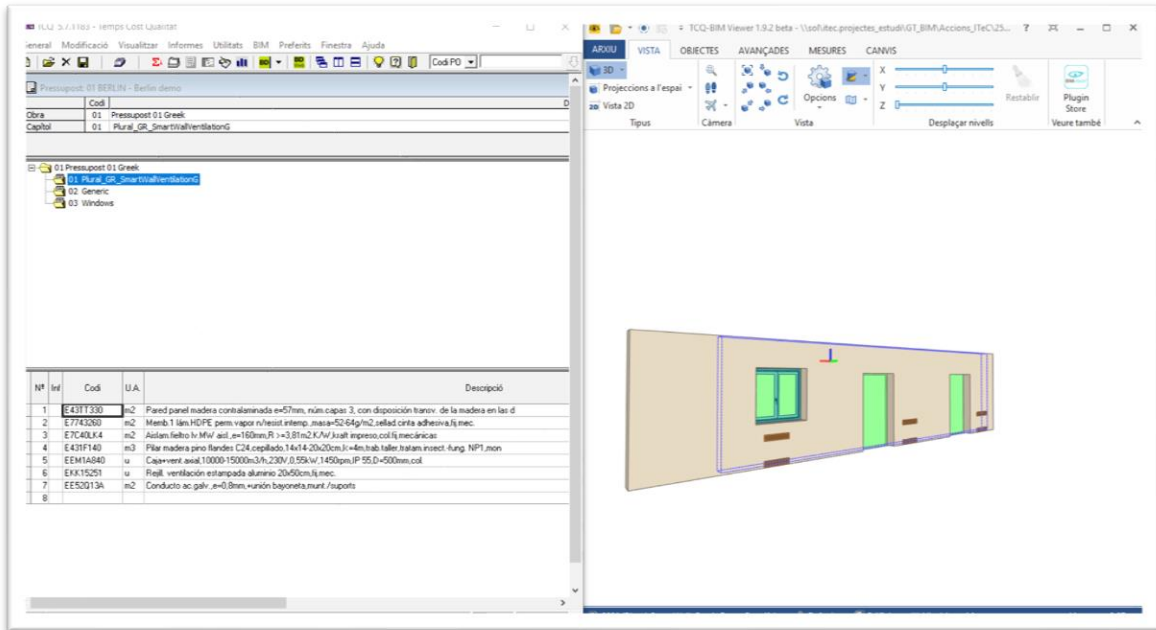
FIGURE 9. VISUALIZATION OF PNU KITS FOR THE GREEK DEMO CASE (VVV)

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FIGURE 10: VISUALIZATION OF PNU KITS FOR THE SPANISH DEMO CASE (TERRASSA)
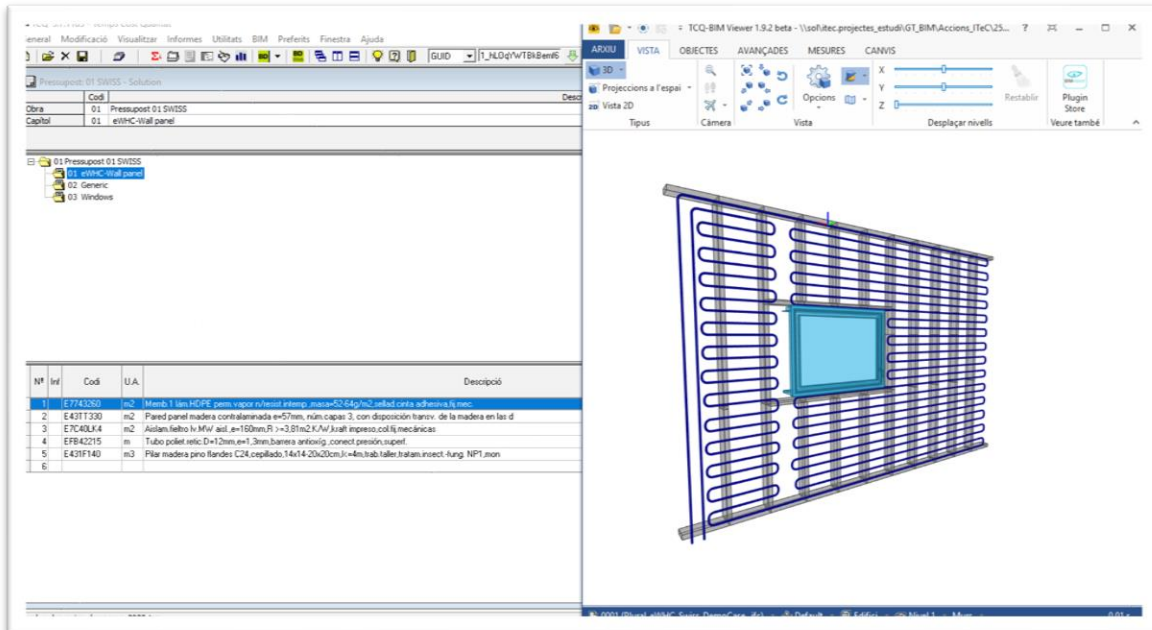
FIGURE 11: VISUALIZATION OF PNU KITS FOR THE SWISS DEMO CASE (BERN)
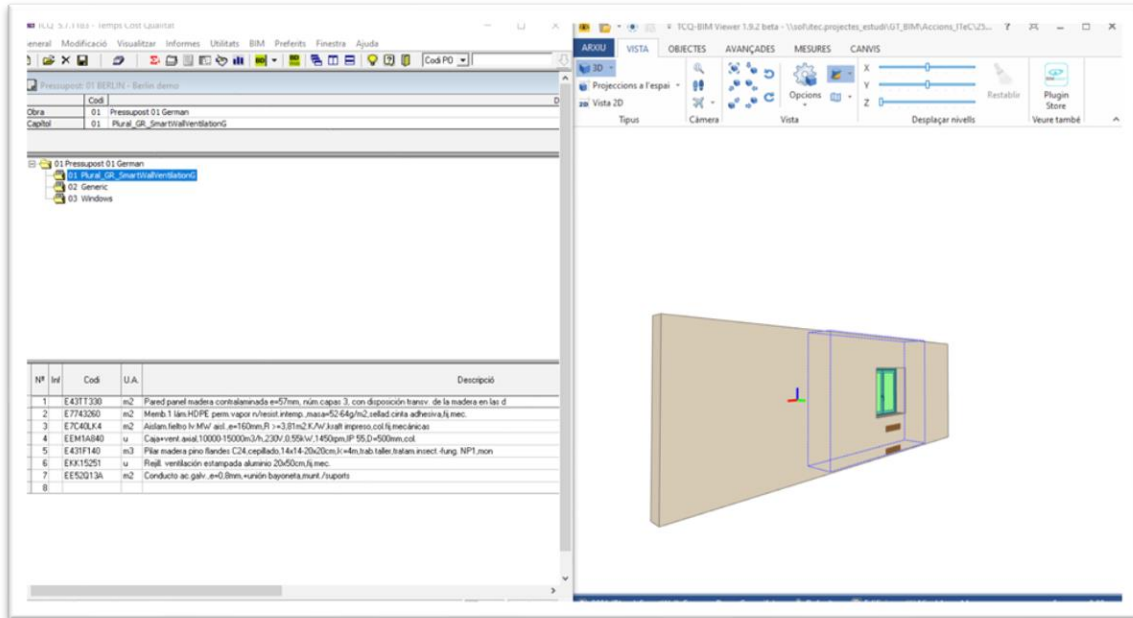
FIGURE 12: VISUALIZATION OF PnU KITS FOR THE GERMAN DEMO CASE (BERLIN)
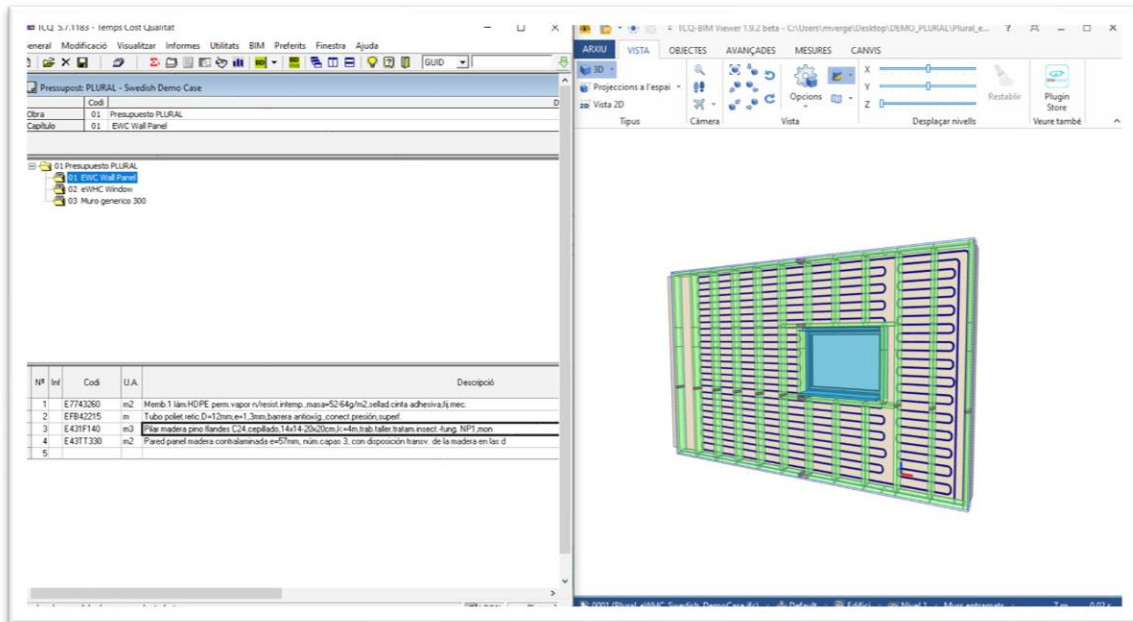
FIGURE 13: VISUALIZATION OF PnU KITS FOR THE SWEDISH DEMO CASE (VASBY)

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Once, the digital model is in the TCQ environment, the various modules can be used to obtain the information needed, e.g., budget, work plan, CO2, etc. Thus, it becomes possible to obtain some KPIs related to the LCA, export them in a spreadsheet format and send them to the LYSIS platform. Furthermore, through this process addition data are made available and can be used to calculate other KPIs in the T8.1. In a future step, the additional KPIs could be added in the same spreadsheet and also incorporated in the LYSIS platform.

3.4   Calculated environmental KPIs

Table 2 lists the environmental performance indicators considered in the PLURAL project according to the deliverable "D1.4 – Key performance indicators, system components and performance targets".
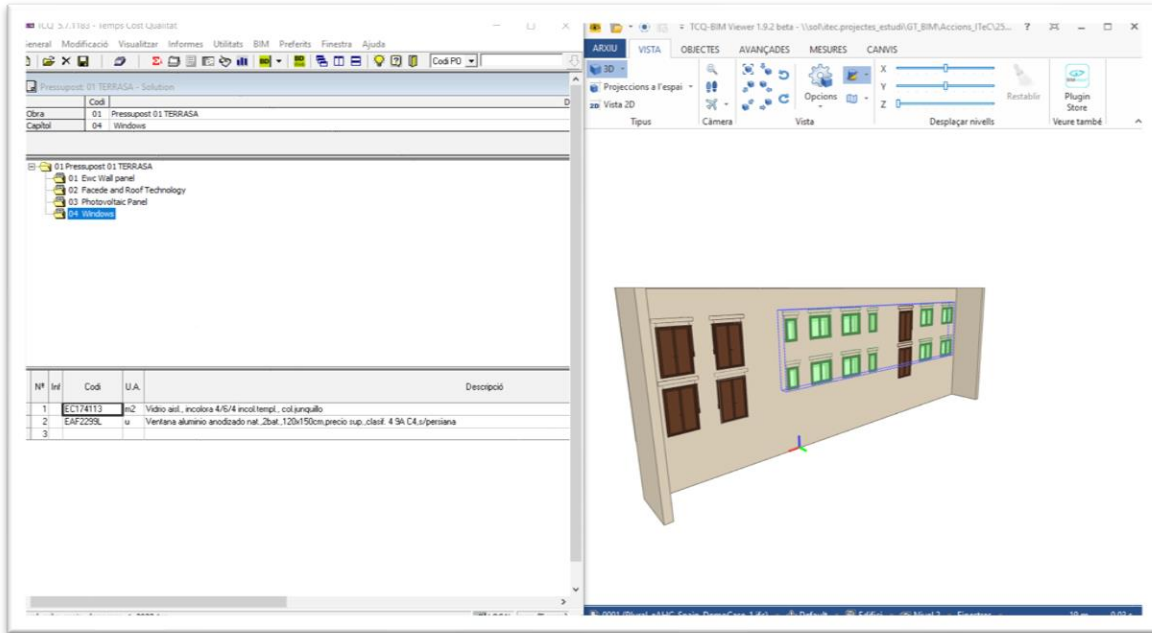
TABLE 2: ENVIRONMENTAL KPIS AND CHANGES MADE (STRIKETHROUGH TEXT)

KPI	Symbol	ID	Description	Unit	Feature	Component
Global Warming Potential	GWP100	4.3.1	A measure of greenhouse gas emissions, including Product and Construction stage (A1-A5), as well as Use stage (B1-B7). Baseline model of 100 years of the IPCC [14]	$kgCO_{2eq}/m^2$	SIM (TCQiGMA-ITeC)	~~Building level~~ PNU kit level
Total Primary Energy Demand	PED	4.3.2	Total Primary Energy use (renewable and non-renewable).	MJ/m^2	SIM (TCQiGMA-ITeC)	~~Building level~~ PNU kit level
Depletion of abiotic resources – elements	DAR-el	4.3.3	A measure of the depletion of nonliving (abiotic) resources such as minerals and metals.	kg Sb-eq/m^2	SIM (TCQiGMA-ITeC)	PNU kit level
Depletion of abiotic resources – fossil fuels	DAR-fos	4.3.4	A measure of the depletion of nonliving (abiotic) resources such as fossil fuels.	MJ-eq/m^2	SIM (TCQiGMA-ITeC)	PNU kit level
Energy efficiency	EE	4.3.5	A measure of how much energy is required per product output. It is defined as specific energy consumption of fuels (e.g., NG) and electricity to Production ratio.	kWh/m^2	SIM (TCQiGMA-ITeC)	PnU kit level
Specific CO$_2$ emissions	EmCO2	4.3.6	Local CO2 emissions to production ratio for the manufacturing of each PnU kit (pre-installation).	~~g/m^2~~ kg/m^2	SIM (TCQiGMA-ITeC)	PnU kit level

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Recyclability	Rec	4.3.7	• Components for reuse • Materials for recycling • Materials for energy recovery Percentage of recycled content of the materials used	Kg/m² %	SIM (TCQiGMA-ITeC)	PnU kit level
% Disassembly of the solution	Dis	4.3.8	A value for each material (0-1) of the property of disassembly. Each product (made up of materials) has a % of disassembly from the result of the materials that component the product.	%	SIM (TCQiGMA-ITeC)	PnU kit level

The above KPIs can be calculated directly by applying the integrated TCQ methodology described in the previous sections. However, at the current phase of the project it is not possible to present the full list as some of the KPIs require the completion of task T8.1, which is still ongoing.

These indicators are the ones that require the phases of use or the inclusion of actual values from manufacturers or installers. Some adjustments and comments on the calculated KPIs are listed below:

- **Global Warming Potential (GWP):** It was decided to change the calculation of this KPI to evaluate it for the PnU kit level instead of the building level, which was originally proposed in D1.4. For the first phase, the result of this indicator includes only the Product and Construction stage. Once T8.1 will be completed, the values for the Use stage will be also added.

- **Total Primary Energy Demand:** It was decided to change the calculation of this KPI to evaluate it for the PnU Kit level instead of the building level, which was originally proposed in D1.4.

- **Specific CO2 emissions:** This indicator provides information on *local* CO2 emissions in the manufacture of each PnU kit unlike the Global Warming Potential which gives the emissions at *global* level. In this case, we consider the emissions of the assembly plant. The emissions will be due to the machinery needed to assemble the kits and will be obtained from the data used for the GWP KPI. This indicator is reported in kg/m2 instead of g/m2 for consistency with the applied software.

- **Recyclability:** The values described for this KPI cannot be calculated directly with the TCQi software and thus it is not a calculation that can be integrated into the TCQ – MODEST-LYSIS solution directly. The original description for (a) Components for reuse, (b) Materials for recycling, and (c) Materials for energy recovery refers to data included in an EPD

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(Environmental Product Declaration) where the most accurate information is provided by the manufacturer itself. Instead, it was proposed to modify this indicator's definition and calculate the percentage of recycled content of the materials used. In this case, manufacturer's data can improve it, but the BEDEC database will incorporate default values. Thus, the values are obtained in percentages without referencing them to the m^2 of kit required.

In the following, Table 3 presents the value of each KPI for PnU kit and demo site combinations. It also shows the square meters of façade to obtain the indicator in these units. This set of data has currently been sent and incorporated in the LYSIS platform.

TABLE 3: CALCULATED KPIS FOR PNU KIT-DEMO SITE COMBINATIONS

PNU kit	Demo site	KPI	KPI symbol	ID	Unit	m²	Result	KPI/ m²
Hybridwall	Terrassa	Global Warming Potential (A1-A5)	GWP100	4.3.1	kgCO2 eq/ m²	228,95	18.650,07	81,46
Hybridwall	Terrassa	Total Primary Energy Demand	PED	4.3.2	MJ/m²	228,95	242.998,17	1.061,36
Hybridwall	Terrassa	Depletion of abiotic resources – elements	DAR-el	4.3.3	kg Sb-eq/ m²	228,95	0,11	0,00
Hybridwall	Terrassa	Depletion of abiotic resources – fossil fuels	DAR-fos	4.3.4	MJ-eq/ m²	228,95	158.696,70	693,15
Hybridwall	Terrassa	Specific CO_2 emissions	EmCO2	4.3.6	kg/m²	228,95	187,53	0,82
Hybridwall	Terrassa	Recycled Content	Rec	4.3.7	%	228,95	0,70	0,70
SmartWall	VVV	Global Warming Potential (A1-A5)	GWP100	4.3.1	kgCO2 eq/ m²	29,544	3.432,35	116,18
SmartWall	VVV	Total Primary Energy Demand	PED	4.3.2	MJ/m²	29,544	536.033,31	18.143,56
SmartWall	VVV	Depletion of abiotic resources – elements	DAR-el	4.3.3	kg Sb-eq/ m²	29,544	0,03	0,00
SmartWall	VVV	Depletion of abiotic resources – fossil fuels	DAR-fos	4.3.4	MJ-eq/ m²	29,544	35.436,90	1.199,46
SmartWall	VVV	Specific CO_2 emissions	EmCO2	4.3.6	kg/m²	29,544	19,71	0,67
SmartWall	VVV	Recycled Content	Rec	4.3.7	%	29,544	0,94	0,94
ConExWall	Kasava	Global Warming Potential (A1-A5)	GWP100	4.3.1	kgCO2 eq/ m²	71,96	5.690,50	79,08
ConExWall	Kasava	Total Primary Energy Demand	PED	4.3.2	MJ/m²	71,96	699.923,58	9.726,56

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ConExWall	Kasava	Depletion of abiotic resources – elements	DAR-el	4.3.3	kg Sb-eq/ m²	71,96	0,00	0,00
ConExWall	Kasava	Depletion of abiotic resources – fossil fuels	DAR-fos	4.3.4	MJ-eq/ m²	71,96	58.327,30	810,55
ConExWall	Kasava	Specific CO_2 emissions	EmCO2	4.3.6	kg/m²	71,96	228,96	3,18
ConExWall	Kasava	Recycled Content	Rec	4.3.7	%	71,96	0,97	0,97
ConExWall	Vasby	Global Warming Potential (A1-A5)	GWP100	4.3.1	kgCO2 eq/ m²	23,468	2.673,81	113,93
ConExWall	Vasby	Total Primary Energy Demand	PED	4.3.2	MJ/m²	23,468	34.933,80	1.488,57
ConExWall	Vasby	Depletion of abiotic resources – elements	DAR-el	4.3.3	kg Sb-eq/ m²	23,468	0,01	0,00
ConExWall	Vasby	Depletion of abiotic resources – fossil fuels	DAR-fos	4.3.4	MJ-eq/ m²	23,468	19.871,14	846,73
ConExWall	Vasby	Specific CO_2 emissions	EmCO2	4.3.6	kg/m²	23,468	47,04	2,00
ConExWall	Vasby	Recycled Content	Rec	4.3.7	%	23,468	0,78	0,78
SmartWall	Berlin	Global Warming Potential (A1-A5)	GWP100	4.3.1	kgCO2 eq/ m²	25,61	1.274,88	49,79
SmartWall	Berlin	Total Primary Energy Demand	PED	4.3.2	MJ/m²	25,61	32.398,84	1.265,28
SmartWall	Berlin	Depletion of abiotic resources – elements	DAR-el	4.3.3	kg Sb-eq/ m²	25,61	0,00	0,00
SmartWall	Berlin	Depletion of abiotic resources – fossil fuels	DAR-fos	4.3.4	MJ-eq/ m²	25,61	11.835,42	462,21
SmartWall	Berlin	Specific CO_2 emissions	EmCO2	4.3.6	kg/m²	25,61	16,41	0,64
SmartWall	Berlin	Recycled Content	Rec	4.3.7	%	25,61	0,90	0,90
ConExWall	Bern	Global Warming Potential (A1-A5)	GWP100	4.3.1	kgCO2 eq/ m²	25,224	1.582,40	62,73
ConExWall	Bern	Total Primary Energy Demand	PED	4.3.2	MJ/m²	25,224	271.007,06	10.744,02
ConExWall	Bern	Depletion of abiotic resources – elements	DAR-el	4.3.3	kg Sb-eq/ m²	25,224	0,01	0,00
ConExWall	Bern	Depletion of abiotic resources – fossil fuels	DAR-fos	4.3.4	MJ-eq/ m²	25,224	15.957,21	632,62
ConExWall	Bern	Specific CO_2 emissions	EmCO2	4.3.6	kg/m²	25,224	15,71	0,62
ConExWall	Bern	Recycled Content	Rec	4.3.7	%	25,224	0,94	0,94

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4. Conclusions

We have presented the methodology required for the flexible, efficient, and secure deployment of the LYSIS-MODEST platform, followed by a more detailed description of the process related to the integration of the TCQ methodology with LYSIS-MODEST.

The LYSIS-MODEST platform is designed and built as a generic platform for deep building renovation projects with nZEB targets using the three PnU technologies developed in the project. Internally, it incorporates several subsystems with a variety of characteristics in terms of processing capabilities, storage, memory and security. Finding the right balance between all the requirements is not an easy task since many aspects are highly dependent on the specific use case needs. For instance, the exact setup used for the PLURAL project may not be sufficient for a more demanding project with more pilot sites and with different kinds and amount of monitoring and simulation data. On the other hand, the same setup could be considered an overkill for another type of project. In any case, the important thing is that the basic principles of the presented methodology remain the same. Thus, following the described guidelines and making slight adjustments would always result in highly available, secure and performant systems that can sufficiently support deep building renovation projects.

In addition, the creation of BIM models for the different PnU kits offered in the PLURAL project, has enabled the design of a methodology that integrates the LYSIS-MODEST platform with TCQ. The combination of IFC models with the different TCQ modules and the BEDEC database provides the ability to manage the construction process in all the phases of its life cycle to obtain the desired information such as budget and work plan, economic monitoring, quality control plan, health and safety plan, CO_2 emissions and energy consumptions. Applying the resulted integrated methodology, part of the environmental key performance indicators has been calculated, especially KPIs belonging to the first phases of the life cycle that can be obtained in a generic way from the BEDEC database. In all cases, the manufacturers can improve these data through the introduction of the respective information in EPDs. The relevant KPIs calculated at this stage of the project have been successfully integrated in the LYSIS-MODEST platform and can be visualized using the MODEST UI tool.

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