Enabling Innovative Space-driven Services for Energy Efficient Buildings and Climate Resilient Cities

D3.2 BUILDSPACE core platform and services (interim)

October 2024

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Abbreviations and acronyms

Acronym	Description
2D	Two dimensions
3D	Three dimensions
4D	Four dimensions
ADS	Atmosphere Data Storage
API	Application Programming Interface
AR	Augmented Reality
BGI	Blue-Green Infrastructure
BIM	Building Information Model
BVC	Buildings Value Chain
CDD	Cooling Degree Days
CDS	Climate Data Storage
CGAL	Computational Geometry Algorithms Library
CKAN	Comprehensive Knowledge Archive Network
CLMS	Copernicus Land Monitoring Service
CMIP6	Coupled Model Intercomparison Project Phase 6
CWS	Copernicus Web Services
D	Deliverable
DEM	Digital Elevation Model
DH	District Heating
DHW	Domestic Hot Water
DT	Digital Twin
DSM	Digital Surface Model
DTM	Digital Terrain Model
EGNSS	European Global Navigation Satellite System

Acronym	Description
EPC	Energy Performance Certificate
gDT	geometric Digital Twin
GIS	Geographical Information System
GUI	Graphical User Interface
HAS	High Accuracy Service
HDD	Heating Degree Days
HTTP	Hypertext Transfer Protocol
IFC	International Foundation Class
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicator
LiDAR	Light Detection and Ranging (or Laser Imaging Detection and Ranging)
M	Month
NDVI	Normalized Difference Vegetation Index
NTRIP	Networked Transport of RTCM via Internet Protocol
NUTS	Nomenclature of Territorial Units for Statistics
OSM	OpenStreetMap
PCD	Point Cloud Data
PCL	Point Cloud Library
PLY	PoLYgon file format
PV	Photovoltaic
QM	Quantile Mapping
RANSAC	Random Sample Consensus
RCP	Representative Concentration Pathway
RGB	Red, Green, Blue

Acronym	Description
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SE	Service
SLAM	Simultaneous Localization and Mapping
SSP	Shared Socioeconomic Pathway
TRL	Technology Readiness Level
UAC	Urban Atlas Cover
UAV	Unmanned Aerial Vehicle
UC	Use Case
UCZ	Urban Climate Zones
UHE	Urban Heat Exposure
UHI	Urban Heat Island
UHR	Urban Heat Risk
UHV	Urban Heat Vulnerability
UI	User Interface
VR	Virtual Reality
WP	Work Package
XML	Extensible Markup Language
YOLO	You Only Look Once

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Executive summary

The BUILDSPACE project aims to support the Green Deal objectives by enhancing **buildings' energy efficiency** and **urban resilience** through **innovative digital solutions**. The project offers services that allow stakeholders to interact with building digital twins (DT) and develop strategies for sustainability and climate resilience, focusing on energy performance, urban heat and flood risks. These services are delivered via a core platform that integrates heterogeneous data sources, such as IoT systems, aerial imagery and satellite data from EGNSS and Copernicus, while offering user management.

This report presents the second technology release of the BUILDSPACE core platform and its five services. In the **core platform**, significant advancements have been made in both **backend and frontend** development, particularly integrating Copernicus and EGNSS Galileo services and developing a Python client to facilitate the usage of the platform APIs.

The services are divided into building-scale and city-scale categories:

- At the **building scale**, the **Digital Twin Generation (SE1)** service further automates the creation of geometric DTs, incorporating machine learning to enhance object detection and relationships. The **Digital Twin Enrichment (SE2)** service focuses on detailed building-scale data, combining UAV-acquired imagery and SLAM-based internal models to detect thermal anomalies such as cracks and moisture in building envelopes. Both services continue to be validated across pilot cases, with improvements in data accuracy and visualisation workflows.
- At the **city scale**, the **Built Environment Climate Scenarios (SE3)** service assesses current and future energy demand in buildings based on climate scenarios. It provides tools for evaluating retrofitting strategies and solar PV potential to support urban decision-making. The **Urban Heat Analysis and Resilience (SE4)** service evaluates social vulnerability to heat, considering demographic factors and microclimatic impacts like the urban heat island (UHI) effect. The **Urban Flood Analysis and Resilience (SE5)** service models flood risks, focusing on building damage and the impact of blue-green infrastructure, supporting climate adaptation strategies for urban stakeholders.

Each service has been customised for pilot applications, with enhancements in workflows and data processing, and will undergo further development for the third and final technology release. The integration of these service into a cohesive platform allows BUILDSPACE to offer a robust decision-support tool for enhancing the resilience and sustainability of Europe's urban environments.

1. Introduction

BUILDSPACE project supports the EU Green Deal by enhancing buildings' energy efficiency and urban resilience using advanced technologies such as satellite data analysis, digital twins, AR/VR, and drones equipped with thermal imaging. These technologies enable services that allow users to interact with a building's digital twin, as well as monitor and strategize the energy performance and climate resilience of urban environments, focusing on thermal conditions and flood risks.

The BUILDSPACE platform integrates data from IoT, BIM, drones and satellite services (e.g., EGNSS and Copernicus) to provide decision support tools for stakeholders across the buildings value chain (BVC). The work package 3 (WP3) "BUILDSPACE location-based and remote sensing applications development" focuses on developing, deploying and validating the platform and its services, offering building monitoring tools for construction, operation and renovation, and linking these to city-scale services for climate change analysis and prediction. The services are both at building level (SE1 and SE2), generating digital twins enriched with thermography data to support construction, renovation and monitoring; and at city level (SE3, SE4 and SE5), supporting energy demand analysis, urban heat and flood risk management.

The services will be implemented across four EU pilot locations (Figure 1).

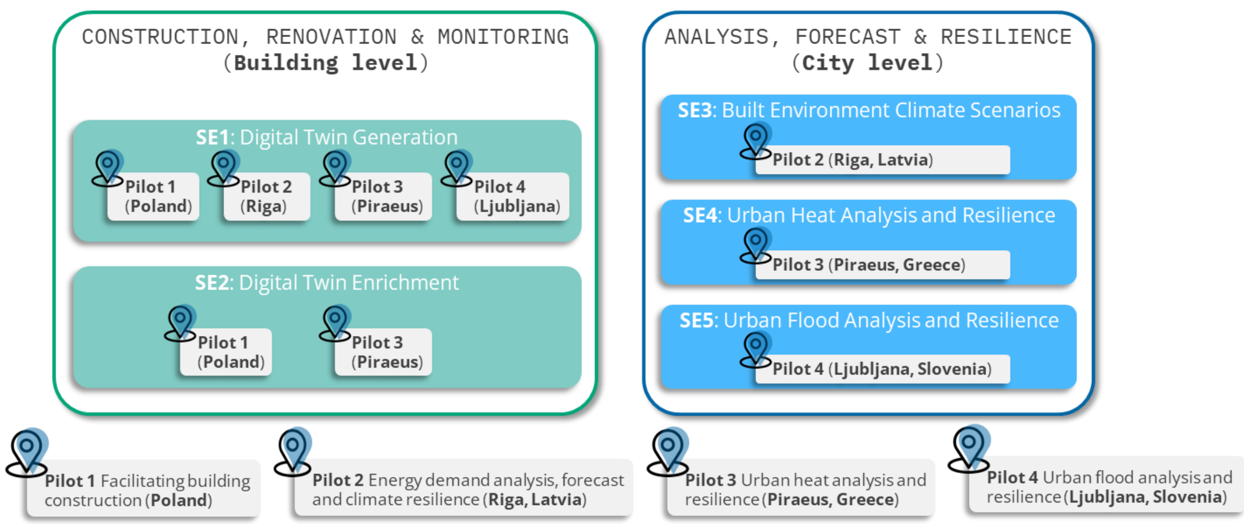


Figure 1. BUILDSPACE services and pilots' relation

The development follows three iterative cycles, with releases schedules in project months 13, 21 and 28, as can be seen in Figure 2. In the present report, the second technology release is informed in the following sections (section 2 to section 6).

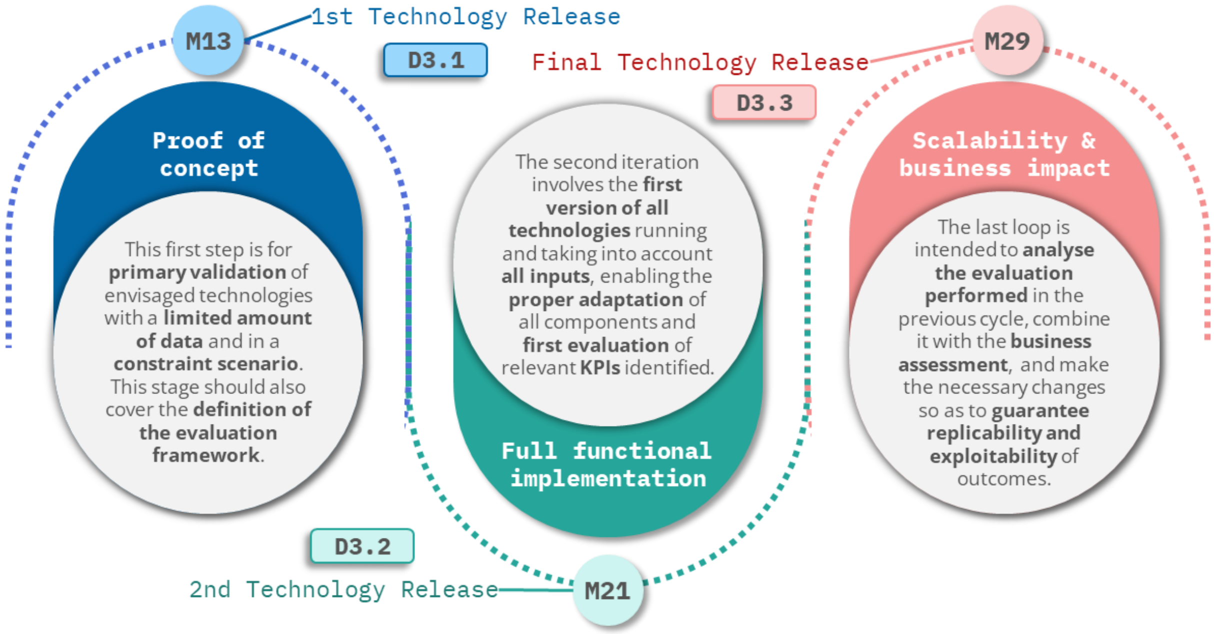


Figure 2. BUILDSPACE methodology of iterative cycles of work, technology releases and related deliverables in WP3

WP3 closely collaborates with WP2, which focuses on gathering user requirements, co-creation and aligning with satellite services. As shown in Figure 3, WP2 developed user stories through a process that involved pilot partners. These user stories were expanded to cover a broader range of target groups, providing detailed descriptions, rationale, challenges and data availability. From these user stories, both functional and non-functional user requirements were derived in collaboration with pilots. Service developers also contributed by preparing services descriptions, which helped clarify initial ideas and were essential for generating the use cases. Each service was outlined with its scope, objectives, input requirements, output and workflow. Data needs were categorised as pilot-independent or pilot-dependent for clarity. This process was further enriched through two co-creation sessions involving external stakeholders.

The user stories, user requirements and technical requirements were validated with service providers to ensure alignment with the project's services and activities. This validation led to the creation of technical use cases, integrating all relevant information and service relationships. Service leaders provided feedback using a structured template, ensuring that user requirements matched planned services functionalities, with updates and refinements made as necessary. Additionally, common wireframes and mock-ups were designed to create a cohesive user interface across all services. This process included defining the workflow of each service in collaboration with service leaders, serving as a critical foundation for the final mock-up design of each service application.

Feedback was gathered and incorporated across the two co-creation sessions. The first, held in July 2023, introduced the BUILDSPACE project and its services, gathering feedback on potential end-user challenges and needs, as well as input on visualisations and additional functionalities. This feedback was integrated into the first technology release. The second co-creation session, held in November 2023, engaged a wider audience, including external stakeholders and key pilot participants. It introduced BUILDSPACE's objectives and showcased the main features, functionalities and visualisations of the services. Participants, grouped by their service of interest, provided feedback on workflows, visualisations, comparison tools and practical applications. This session also fostered synergies with other EU projects and initiatives.

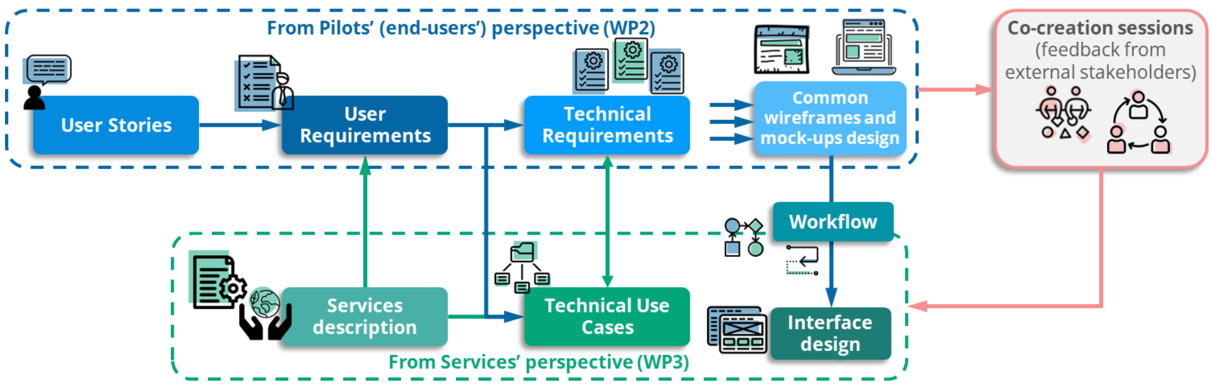


Figure 3. WP2 process from the elicitation of the user stories to the identification of user requirements, technical requirements and use cases

The outcomes of these co-creation sessions, along with the ongoing feedback, were essential for developing the technical use cases and service specifications. This collaborative approach ensured that the services developed were robust, user-focused and aligned with the BUILDSPACE project's objectives.

To ensure a coordinated development and reporting of the core platform and services within WP3, a structured process has been established for deliverables, aligned with the three technology releases. This process includes several key steps that must be addressed. As illustrated in Figure 4, it begins with the service description (linked to earlier work in WP2), followed by the identification of required input data and service outputs. Next, the user experience is designed through workflow development, leading to the application of the service to the BUILDSPACE pilot. Additional steps include assessing the replication potential across Europe and beyond, and finally, advancing the technical development of the service.

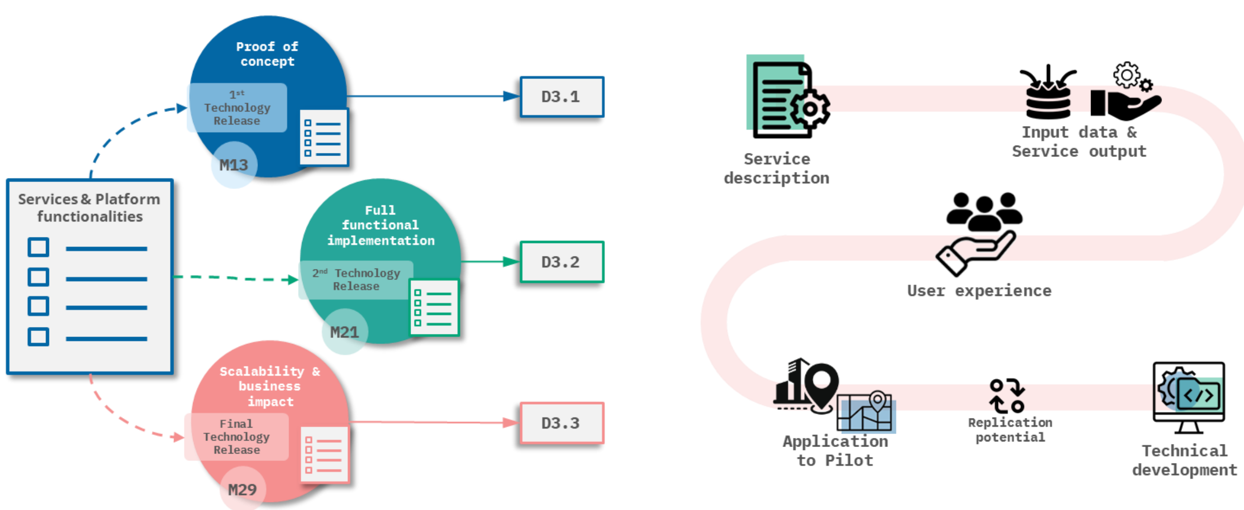


Figure 4. Guided process within WP3 for joint and aligned development of the platform and services. Steps for the definition and reporting of the services

1.1. Deliverable structure

The present deliverable 3.2 "BUILDSPACE core platform and services (interim)" is the second iteration of the BUILDSPACE core platform and services, where the second technological release is reported. The document is **structured** in the following sections:

- **Section 1**, current section, introduces the WP3, the services and respective pilots, as well as the process coming from WP2 and the coordinated development process for the core platform and services within WP3. It also includes the document structure (**1.1**), and the delivery plan for the three technology releases (**1.2**).
- **Section 2** focuses on the BUILDSPACE Core Platform, reporting on the integration layer and front-end development.
- Sections 3 to 6 are devoted to the BUILDSPACE services. These sections are:
    - **Section 3**, which includes the services at building scale: Digital Twin Generation (**SE1**) and Enrichment (**SE2**).
    - **Section 4** covers **SE3**, Built Environment Climate Scenarios, at city scale.
    - **Section 5** is devoted to the service addressing Urban Heat Analysis and Resilience (**SE4**), at city scale.
    - **Section 6** includes **SE5**, Urban Flood Analysis and Resilience, at city scale.

  Each of these sections includes a description of the service, and following sub-sections:
    - **Sub-section X.1** includes input data needed by the service as well as service output or results.
    - **Sub-section X.2** includes an overview of the benefits of the service to the defined different target groups or end-users. It also describes service functionalities with a user or service workflow from the user's perspective.
    - **Sub-section X.3** describes how the service is tailored to each pilot, addressing specific needs identified through feedback received, unique data utilised and other key customisations. This section also explores the service's replication potential, along with any constraints affecting broader application and usage across Europe.
    - **Sub-section X.4** delves into the technical developments made for the second technology release, highlighting changes and progress since the first release. It details the work complete to date and provides links to the deployed developments.
    - **Sub-section X.5** reports on what is missing to finalise the service, the planned next steps and processes towards the third and last technology release. It also includes how the second release will be validated with the pilot partners.

- **Section 7** includes an overview of the **progress made** towards the related objectives 2 and 3 from the Grant Agreement, as well as the next steps to face the final technology release.
- **Section 8** provides the **conclusions** of the document.

1.2. Technology releases delivery

As already reported in D3.1 for the organisation of the delivery of the platform and services throughout the three technology releases, the following Table 1 includes a "Functionalities" column listing the different functionalities for the platform and services, with an assigned number that is referenced in the "releases" columns. Then, in the three columns for the technology releases, the different numbers are referenced to point out the functionalities that will be released in each one. Some clarifications next to the bullet number points are made to make clear if the functionality will be ready for the release but only partly, or with simplified or initial elements.

Table 1. Relation of the platform and services with what will be delivered in each technology release

Function / Service	1st Technology Release (delivered in M13 – D3.1)	2nd Technology Release (current delivery M21 – D3.2)	Final Technology Release (final delivery M29 – D3.3)
Core Platform	- **Identity provisioning** fully deployed - **Data storage and data management** (upload/ download/ update) fully deployed - **Data sharing** mechanisms fully deployed - **Folder functionalities** (creation of folders, upload files in certain folders, etc.) fully deployed and tested - **Integration of Copernicus** Land, Atmosphere, Climate Change services fully developed and initially tested	- **Intuitive User Interface (UI) for visualisation** fully developed and initially tested - **Data sharing mechanisms** completely tested - **Integration of Copernicus services** completely tested - **Integration of EGNSS Galileo HAS** fully developed and initially tested - **Search of datasets** throughout all BUILDSPACE services fully developed and initially tested	- **Intuitive User Interface (UI) for visualisation** completely tested - **Integration of EGNSS Galileo HAS** completely tested - **Search of datasets** throughout all BUILDSPACE services completely tested
SE1	- Segmentation of the **3D point cloud model** initial test - **gDT generation of indoor environment, façade and roof** initial test - gDT generation of **construction phase** user requirements definition	- Segmentation of the **3D point cloud model** technical development - **gDT generation of indoor environment, façade and roof** technical development - gDT processing of **construction phase** initial testing - **EGNSS data** integration initial testing - **VR/AR** support gDT **visualisation** initial testing	- gDT generation of **construction phase** development - **EGNSS data** integration final development - **Screen-based mode gDT visualisation** final development - **VR/AR** support gDT **visualisation** final development
SE2	- **RGB point cloud** generation from photogrammetry and SLAM first processing result - **Thermal point cloud** generation from	- **RGB point cloud** final results - **Thermal point cloud** final results - Identification of **thermal bridges in the external envelope,** categorisation and	- Identification of **thermal bridges in the external envelope,** categorisation and report generation final results - Identification of **dampness in the external envelope,**

Function / Service	1st Technology Release (delivered in M13 – D3.1)	2nd Technology Release (current delivery M21 – D3.2)	Final Technology Release (final delivery M29 – D3.3)
	photogrammetry **first processing result**	report generation **first processing results** - Identification of **dampness in the external envelope,** categorisation and report generation **first processing results** - Identification of malfunctioning cells in **solar panel installation** and categorisation of panels according to performance **first processing results**	categorisation and report generation **final results** - Identification of malfunctioning cells in **solar panel installation** and categorisation of panels according to performance **final results** - **Visualization tool** (website – link) for each pilot **final results**
SE3	- Estimation of the **energy demand** of the residential building stock **in a district** - Energy demand representation in a **coloured-based map in a district** (simplified version) - Assessment of **solar PV potential** of building rooftops **in a district** (yearly output)	- Estimation of the **energy demand** of the residential building stock **final city results** - Estimation of the energy demand in **future climate change scenarios final results** - Energy demand representation in a **coloured-based map final results** - **GUI** for user-friendly interface, **map-based visualisation developed for functions so far** - Assessment of **solar PV potential** of building rooftops **final city results** (hourly output)	- **GUI** for user-friendly interface, **map-based visualisation developed for all functions, tested** - Calculation of KPIs for **energy retrofitting strategies** (impact of energy efficiency measures) **final results** - Integration of **solar PV potential** in the service application **final integration** - Final testing and feedback gathering for all service functionalities
SE4	- **Test of systematisation** of data downloading and data management for the **urban heat vulnerability**, urban heat **exposure** and urban heat **hazard**. - **Urban heat risk hotspots** identification map **at NUTS region level.**	- Calculation of the **urban heat vulnerability**, urban heat **exposure** and urban heat **hazard, urban heat risk hotspots** identification map and identification of **areas with higher adaptation potential** map **at city scale**. - **Adaptation and mitigation strategies initial identification**. - Creation of **long temporal series of temperature and relative humidity** for different **urban climate zones** (**final**). - **Buildings energy demand** calculated **first version.**	- Calculation of the **urban heat vulnerability**, urban heat **exposure** and urban heat **hazard, urban heat risk hotspots** identification map and **adaptation and mitigation strategies portfolio at district level**. - Identification of **areas with higher adaptation potential** map **at district level within hotspots** - **Buildings energy demand** calculated **final version**. - **User-friendly web visualizer final version**

Function / Service	1st Technology Release (delivered in M13 – D3.1)	2nd Technology Release (current delivery M21 – D3.2)	Final Technology Release (final delivery M29 – D3.3)
SE5	- **Expected flood damages to buildings calculated.** - User-friendly **interface (for map-based visualisation) first version.** - **Flood damage hotspots** identification map **developed**. - **Visualisation of expected flood damages developed.** - Calculation for different **rainfall and retrofitting scenarios in a simplified version.**	- **Expected flood damages to buildings**, user-friendly **interface** (for **map-based visualisation**) and **flood damage hotspots identification** map **developed**. - **Visualisation** of expected flood damages and runoff to land use areas **by graphs and tables partially developed.** - Calculation for different **rainfall and retrofitting scenarios using national climate change.** - **Identification of** adaptation instructions for **guidance**.	- **Calculated:** expected flood damages to buildings**, blue-green factor** to land use areas**, runoff** to land use areas**, different rainfall and retrofitting scenarios.** - User-friendly **interface** (for **map-based visualisation) final version.** - **Flood damage hotspots** and **flood vulnerability hotspots** identification map **final version**. - **Visualisation of expected flood damages** and **runoff** to land use areas **by graphs and tables final version.** - **Guidance with adaptation instructions final version.**

2. BUILDSPACE Core Platform

In this iteration of the BUILDSPACE Core Platform, significant advancements have been made in both the backend and frontend. On the backend, the improvements focus on the integration layer, as demonstrated in the following Figure 5, by completely integrating the Copernicus and GNSS Galileo services. On the frontend, a Python client has been developed to interface with both the Core Platform API and the Account API, of the integration and identity management layers, respectively. Additionally, work has commenced on the user interface of the web application for the Core Platform.

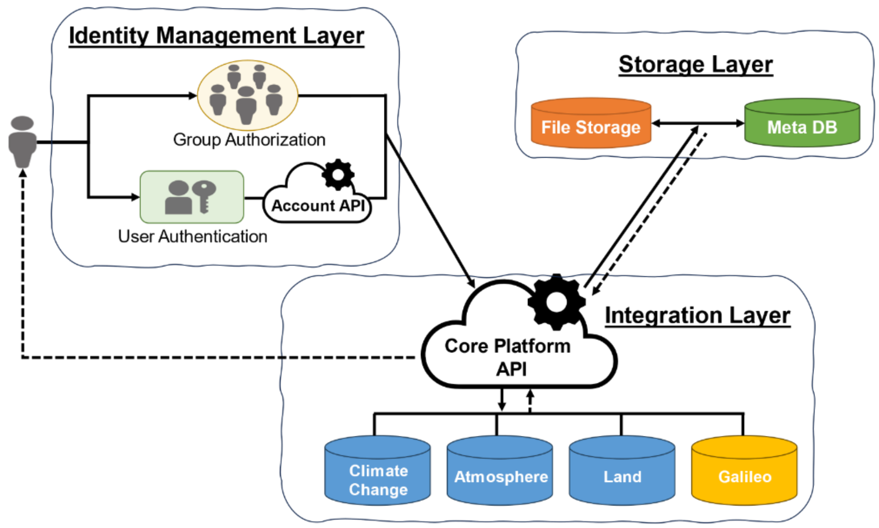


Figure 5. Core Platform's architecture (from D3.1)

2.1. Integration Layer (backend)

2.1.1. Copernicus integration

In the latest iteration of the Core API, the full integration of the Copernicus Climate Change and Atmosphere services was successfully achieved, marking a significant advancement in the platform's functionality. This comprehensive integration has been carefully designed to make a wide array of datasets seamlessly accessible, providing users with an enriched and unified experience. By consolidating these critical services within the Core API, we have not only expanded the data availability but also ensured that this information can be accessed with ease and efficiency. This integration builds on the solid foundation laid by the previous version of the API, retaining the familiar structure of HTTP requests. Additionally, the Swagger documentation has been updated to include the newly integrated Copernicus features (Figure 6). All of the Copernicus data is stored in a dedicated Copernicus bucket, hosted on MinIO within the same cluster as the Core Platform resources and services, making it accessible to all users of the Core API.

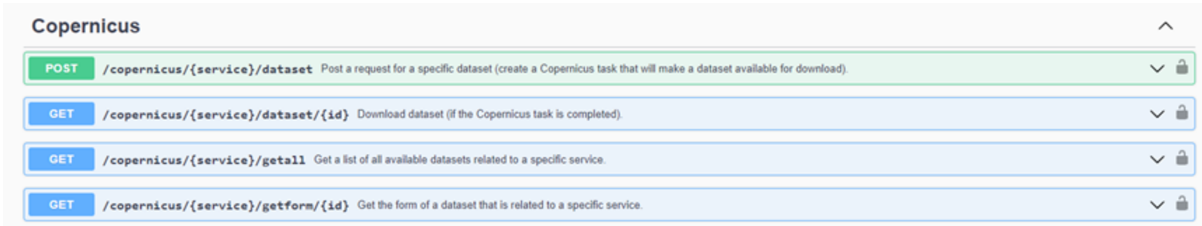


Figure 6. Example of the updated swagger documentation

The integration of the Copernicus services with the Core Platform has been executed with precision, ensuring seamless alignment with the platform's architecture. In more detail, custom data models were developed specifically tailored to the input and output requirements of Copernicus resources, ensuring optimised data handling and promoting security by preventing data leakage, while maintaining interoperability. The workflow for accessing this functionality is straightforward: users begin by requesting and viewing the comprehensive list of datasets available through the Climate Data Store (CDS) or the Atmosphere Data Store (ADS) Copernicus services. Once a dataset is selected, users can then request and access the form data associated with it. This form data contains all the specific requirements and parameters that must be included in an HTTP request to access the dataset. Understanding these parameters is essential for users, as it ensures that all necessary information is correctly specified when requesting specific datasets, thereby guaranteeing successful data retrieval.

After the initial setup, the user proceeds by sending an HTTP POST request to the designated Copernicus service endpoint. This request is populated with the necessary data from the form data as presented in the previous step. The request's parameters are encoded to generate a unique fingerprint, which identifies each dataset retrieval request. This fingerprint is essential for determining if a dataset has already been requested and downloaded previously. If a dataset with the same fingerprint is found, the system recognizes it as already available, automatically updating the request status to "completed" and enabling immediate download.

Once a request is processed, the status attribute shows its progress, indicating whether the dataset is still under preparation or is ready for download. When the status is updated to "completed", the dataset is made available for download from the Copernicus Bucket, functioning like a typical file download.

Additionally, users have the capability to continuously monitor the status of their tasks, ensuring they always remain informed of the progress and availability of their requested datasets.

Copernicus services datasets, including from Land (CLMS), Atmosphere (CAMS) and Climate Change (C3S) have been integrated into the BUILDSPACE Core API (Figure 7).

Figure 7. Copernicus services data integration

These datasets are used in services 3, 4 and 5 at city level, as detailed in following Table 2.

Table 2. Utilisation of Copernicus data in city-scale services

SE3: Built Environment Climate scenarios	SE4: Urban Heat Analysis and Resilience	SE5: Urban Flood Analysis and Resilience

- **Data acquisition:** Copernicus **C3S** provides weather data under climate change conditions, following standard accepted CMIP6 scenarios (SSPs-RCPs). Additional in-situ data from weather stations is also integrated for accuracy.
- **Data processing:** Climate data is **downscaled** using a **bias-correction Quantile-Mapping** procedure, calibrated with 30-years of historical weather station data.
- **Application:** The processed climate data is used in the **energy demand estimation algorithm,** supporting **future scenario modelling** and comparison with historical baselines.
	- **Data acquisition:** Copernicus datasets used for urban heat assessment:
	  - **CORINE Landcover (CLMS)** – land classification.
	  - **NDVI dataset (CLMS)** – vegetation coverage.
	  - **Digital Elevation Model (DEM)**– topographical influences.
	  - **ERA5 hourly data (C3S)** – historical and projected temperature trends.
	- **Data processing**: These datasets enhance the accuracy of **urban heat interpolation models**, supporting localised climate analysis.
	- **Application**: The integrated data contributes to the assessment of **urban heat dynamics and land-use characteristics,** improving resilience planning.
		- **Data acquisition:** The following Copernicus datasets provide spatial and climate-driven hydrological information:
		  - **Copernicus Land (CLMS):** Urban Atlas
		  - **Copernicus Climate Change (C3S)**: climate projections CORDEX (P, Rx1 day) for precipitation and rainfall.
		- **Data processing:** High-resolution **land-use and hydrological modelling data** is integrated to refine flood risk assessments.
		- **Application:**
		  - Expansion of the **FDAM methodology** from national to EU level, utilising Urban Atlas land-use categories.
		  - **Blue-Green Factor analysis,** incorporating using Urban Atlas land-use categories to assess urban water retention capacity.
		  - Climate-driven **hydrology scenarios,** evaluating **precipitation** and **extreme rainfall indices** for assessing blue-green infrastructure impacts.

2.1.1. GNSS Integration

In this iteration of the BUILDSPACE Core Platform, we have successfully integrated the Galileo High Accuracy Service (HAS), European Global Navigation Satellite System (EGNSS), marking a significant advancement in satellite navigation capabilities. Galileo HAS delivers free, real-time, high-precision positioning, making it an invaluable resource for a wide array of users and industries. By utilizing advanced corrections and multi-frequency signals, the service enables highly accurate positioning for critical applications, significantly enhancing efficiency, safety, and performance across diverse sectors such as transportation, agriculture, and telecommunications.

The integration of Galileo HAS into BUILDSPACE was made possible through the Networked Transport of RTCM via Internet Protocol (NTRIP), a specialized communication protocol designed for the dissemination of GNSS data. NTRIP facilitates the real-time transmission of Galileo HAS correction data from a central server, known as a "caster," to a network of clients that request specific data streams. A caster acts as a hub, forwarding these streams to clients based on their requests, ensuring that users receive the precise correction data needed for their operations.

Within the BUILDSPACE environment, we have deployed our own NTRIP caster, accessible at “galileo-buildspace.euinno.eu”. This server is dedicated to provide users with free and secure access to Galileo HAS data streams. Utilizing HTTPS, the system ensures secure data transmission, allowing users to request and retrieve EGNSS correction data in a reliable and encrypted manner. To access these streams, users simply need to configure a client, connect to the BUILDSPACE caster (Figure 8), and use port 443 to download the Galileo HAS data, enabling real-time high-precision positioning for their applications. This seamless integration of Galileo HAS empowers users to harness the full potential of high-accuracy GNSS data, fostering innovation and improving performance in critical industries (Figure 9).

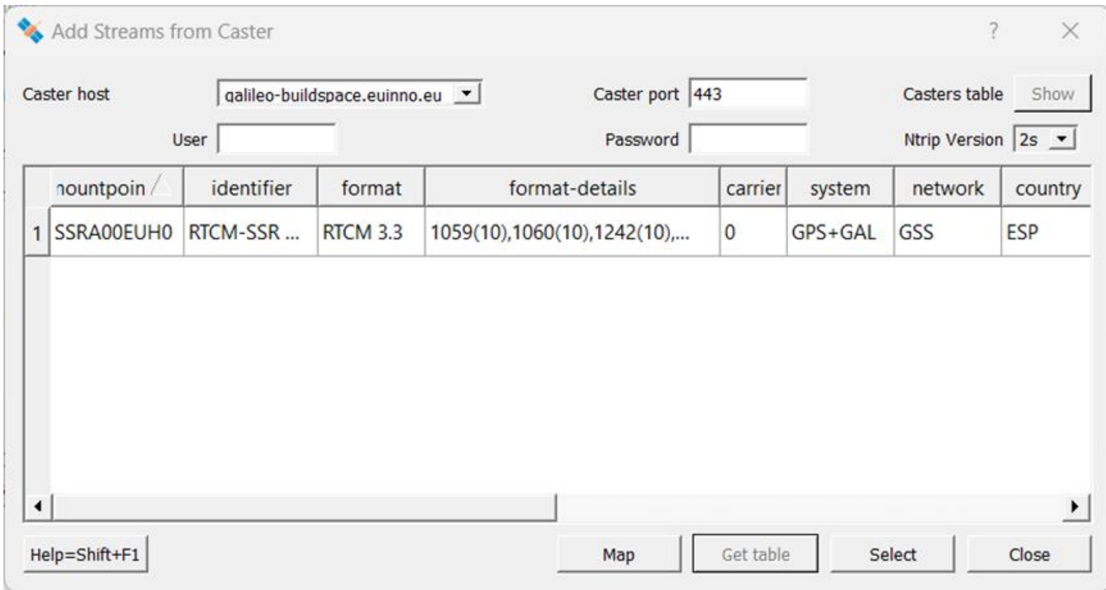


Figure 8. Example of BUILDSPACE Caster Selection

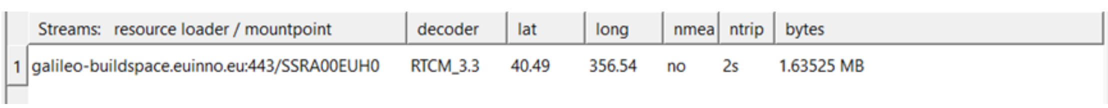


Figure 9. Example of Galileo HAS data steam

2.2. Frontend development

2.2.1. CorePlatPy – The Core Platform Python client

A fully functional, publicly available Python client, CorePlatPy, has been developed for the BUILDSPACE Core Platform. This client provides seamless integration with both the Core Platform API and the Account API, enabling smooth interaction with the platform's features through a user-friendly syntax. The decision to develop CorePlatPy in Python was driven by several important factors. Python's widespread use makes it an ideal choice. Its simplicity and versatility allow users to quickly adopt and integrate the client into their workflows without significant learning curves. Additionally, the selection of Python aligns with the strategic choice to integrate CKAN as the frontend of the platform, providing both the user interface and data cataloguing services. Since CKAN itself is built on Python, the use of a Python-based client that makes interacting with the platform's APIs more efficient, will streamline the entire integration effort.

CorePlatPy offers comprehensive access to all functionalities of the Core Platform, streamlining the development and management process for users. Some of the key functionalities include:

- **User authentication**: Securely authenticate users against the platform (Figure 11).
- **User registration**: Support for registering new users with the platform (Figure 10).
- **Creation of organizations**: Easily create and manage organizations within the platform (Figure 12).
- **Creation of folders**: Organize content by creating folders for different use cases.
- **File management**: Handle file uploads, downloads, deletes and modifications with ease (Figure 13).
- **Content sharing**: Share files in organizations, promoting collaboration.

The following figures (Figure 10, Figure 11, Figure 12 and Figure 13) provide representative examples of the functionalities offered by CorePlatPy, illustrating how the client interacts with both the Core Platform API and the Account API to perform essential tasks.

```
from coreplatpy import Client

client = Client()

client.register()

Email: test-user@example.eu
First Name: Test
Last Name: User
Password: ········
Confirm Password: ········
Profile picture path (can be omitted):
```

Figure 10. User registration

```
from coreplatpy import Client

client = Client()

client.authenticate()

Username: test-user@example.eu
Password: ········
```

Figure 11. User authentication through the CorePlatPy client

```
client.create_organization('Test Organization')

Bucket(id='d21f483d-d56c-441f-89a1-5adc3f0b4db2', name='Test Organization', creation_date=datetime.datetime(2024, 10, 14, 8, 4,
46, 473000, tzinfo=TzInfo(UTC)))

organization_folder = client.get_folder('Test Organization')

organization_folder.upload_file('./just_another_image.JPG', {
    'title':'My Test Image',
    'tags': ['image', 'jpeg']
})

100%|████████████████████████████████████████| 1/1 [00:01<00:00,  1.96s/it]

organization_folder.expand_items_tree()

🗀Test Organization
    🗎My Test Image
```

Figure 12. Create a new organisation, get the organisation's main folder and upload a file through the CorePlatPy client

```
file = organization_folder.get_file(file_name = 'My Test Image')
```

Store File

```
file.store('./')
Multi-Thread Download of My Test Image: 100%|██████████████████████████████████████████| 1/1 [00:05<00:00,  5.81s/it]
```

Download File bytes

```
file_bytes = file.download()
Multi-Thread Download of My Test Image: 100%|██████████████████████████████████████████| 1/1 [00:05<00:00,  5.52s/it]
```

Figure 13. Download a file and either store it in a local copy (store file) or in a local variable (download file bytes)

A more extensive documentation of the CorePlatPy can be found in the official, public, GitHub repository, here.

2.2.2. CKAN – Core Platform's frontend

CKAN, the world's leading, open-source data portal platform, is designed for managing and publishing datasets in a structure and accessible way. Widely adopted by governments, research institutions and organizations, CKAN enables users to create, manage and search datasets via an intuitive web interface or API, supporting both human and machine interaction with data. It includes comprehensive features like metadata management, dataset versioning, data previews, and access control, which simplify data organisation and discovery. CKAN's extensibility through plugins and integrations allows for tailored customisation, while its compatibility with modern data standards and API-driven architecture ensures scalability and flexibility for seamless data sharing and collaboration.

Due to these capabilities, CKAN was selected as the frontend for the BUILDSPACE Core Platform. It enhances data cataloguing and management, allowing efficient data storage, tagging and retrieval with rich metadata, making data easily accessible and reusable. CKAN's advanced search filters, dataset versioning and data preview features further improve usability, particularly for users handling large datasets across various organisations and projects.

For these reasons, integrating CKAN with the BUILDSPACE Core Platform's backend was a strategic choice to establish a solid foundation for dataset management. This integration ensures that users retain full rights over their data on the platform, supported by on-premises infrastructure that upholds data sovereignty while maintaining an intuitive, user-friendly interface. In addition, this integration makes the overall system more robust and boosts the platform's technology readiness level (TRL) by moving it closer to being a fully operational system. Ultimately, the inclusion of CKAN and its integration with the backend enhances the platform's readiness for real-world applications. It strengthens the platform's ability to manage and scale data services, making it a more complete and functional solution that can meet the demands of users and organizations looking for an almost-production-ready, high TRL system.

The integration process is currently underway, with significant progress made on the identity management layer. This component, now nearly complete, enables user authentication and management of both users and organisations directly from the UI. The focus is now on shifting to the integration layer (Figure 5), which will establish the final connection between the backend and frontend, bringing the Core Platform to fill functionality. Figure 14 provides a view of the Core Platform, which is accessible at https://coreplatform-buildspace.euinno.eu/.

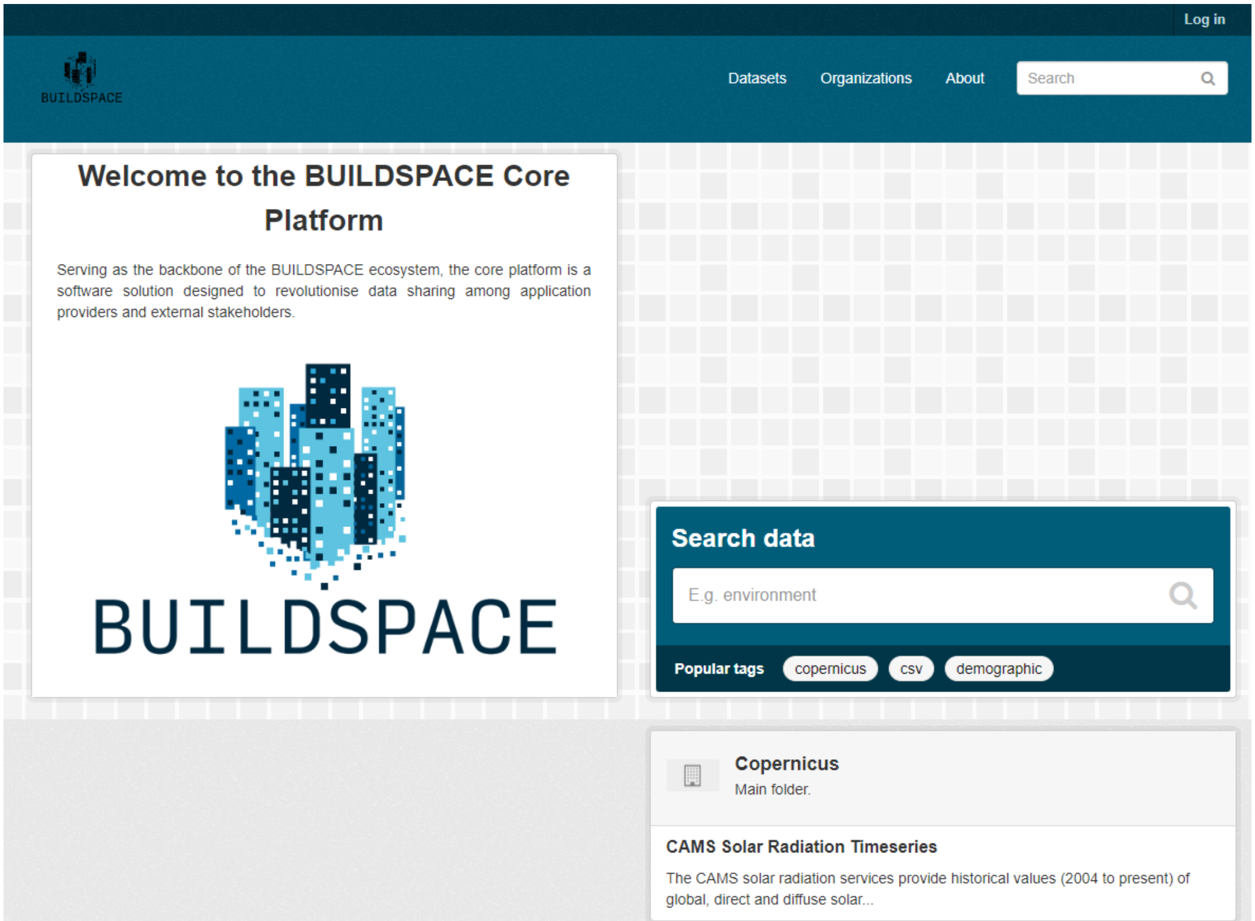


Figure 14. CKAN integrated as frontend of the Core Platform

3. BUILDSPACE services at building scale: Digital Twin Generation and Enrichment

Service 1 (SE1) Digital Twin Generation aims to automatically generate geometric digital twins (DTs) of buildings and link them with EGNSS data for integration into city-scale models, enabling users to visualise the resulting DTs in mixed-reality environments.

In this second technology release, the work continued with the development of the data-driven approaches based on machine learning and AI techniques to automatically detect building objects with acceptable accuracy and extend the framework to detect a larger array of objects. The exploration on the relationships between the objects has been enhanced. The methods are designed to be implemented in the four pilot cases in the BUILDSPACE project. These methods cover **the point cloud data (PCD) processing, opening detection, DT generation, DT updates and DT visualisation**. Among these, the DT visualisation will be developed for the next release. In this report, the other technics will be introduced, and the relative algorithms will be attached.

The Digital Twin Enrichment (SE2) service is designed to provide **detailed building-scale data** using UAVs and SLAM. This service focuses on generating external building models through UAV, capturing RGB and thermal images, as well as inside models based on point clouds generated by SLAM. The integration of these data sources enables the identification and analysis of thermal anomalies in the building envelope, such as cracks, moisture, and faulty solar panels.

Service 2 includes the photogrammetric **reconstruction of RGB images** to generate 3D meshes and exterior point clouds for the pilots in Poland and Greece. Additionally, in Poland, the external point cloud is integrated with internal data obtained via SLAM, providing a comprehensive view of the building. Algorithms are being developed to **project thermal textures** onto the RGB images, resulting in models that combine both thermal and visual data for more detailed analysis.

Furthermore, the service focuses on the **semi-automated detection of critical areas** in building envelopes. This includes identifying **cracks**, detecting **malfunctional solar panels** by locating faulty cells, and recognizing **moisture** and **thermal bridges** using statistical models and classification algorithms. The results of these analyses will be presented in downloadable reports, providing key information on the condition of the building envelope.

The two main objectives of SE2 are to **optimize drone flight protocols**, reducing time and data acquisition costs by efficiently capturing both RGB and thermal images, and to advance the automation of **critical area detection using artificial intelligence**. This will improve the accuracy and efficiency of building inspections, supporting the evaluation of building envelope conditions in both rehabilitation and new construction projects.

3.1. Input and output

3.1.1. SE1 – Digital Twin Generation

The **inputs** used by the SE1 are shown below according to different pilot cases:

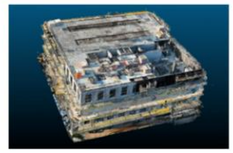
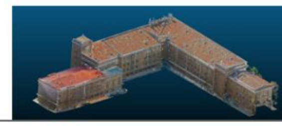
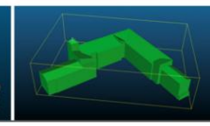
Pilot	Raw Data Source	Data Input	Reference
1 - MOS	Images from drone & ifc model	PCD and as-designed IFC model	 
2 - RPR	Point cloud from terrestrial laser scanner and airborne scanner & .obj data	PCD with xyzrgb	 
3 - MOP	Images from drone	PCD with xyzrgb	
4 - IMZI	Images from drone	PCD with xyzrgb	

Figure 15. Input data of the four pilot projects for SE1

The **outputs** used by the SE1 are:

- **Geometric digital twin**: automatically generated from the point cloud data, this model will capture the precise geometry of the building. The output of the DT is .IFC in this project.
- **Updated digital twin**: the DT is progressively updated to reflect construction phases by comparing the as-designed BIM model with scanned point cloud data. This process enriches the digital twin with monitoring construction progress information.
- **Mixed reality visualisation**: the resulting digital twin will be visualizable through mixed reality environments (in pilot 1) and screen-based solution (in pilot 2, 3 and 4), allowing users to explore and interact with the building's geometry in an immersive setting.
- **EGNSS-linked digital twin:** The project leverages EGNSS data from the Galileo system to precisely locate and georeferenced a generated gDT model, which is derived from high-accuracy point cloud data captured by LiDAR scanning equipment, drones, or near-range scanning technologies. The resulting gDT model is integrated into a GIS platform, allowing for detailed visualization of the model in the context of its surrounding buildings (see figure 16). By incorporating accurate positioning data from the Galileo system, the gDT model provides a spatially precise representation of the environment.

Figure 16 Integration of gDT and GIS environment based on EGNSS data

3.1.2. SE2 – Digital Twin Enrichment

The **inputs** used by the SE2 are the following:

- External images of the buildings, including both RGB and thermal data, captured by UAVs.
- Internal point clouds obtained through scanning technology, specifically laser scanning devices, for detailed interior mapping.
- Georeferenced coordinates using ground control points to accurately align and position the building models within the digital twin.
- Weather data collected during UAV flights, including sky conditions, temperature, and humidity, complemented by local meteorological data to support the interpretation of thermal information.

The **outputs** of the SE2 are as follows:

The service generates RGB and thermal point clouds of the building's exterior, offering a 3D representation that combines visual and thermal information. This allows for detailed analysis of the building's façade from both perspectives. Additionally, the service produces exterior mesh models, creating comprehensive visualizations of the building's surface. These models facilitate a better understanding of the building's envelope, incorporating both thermal and visual details.

Furthermore, the service includes the identification of critical areas in the building's envelope. This includes detecting cracks using RGB and thermal imagery, identifying thermal bridges through analysis of thermal data, and recognizing moisture issues with the aid of thermal and statistical models. Each critical area is thoroughly analysed to provide actionable insights.

Finally, the service detects malfunctioning solar panels, pinpointing defective cells within rooftop installations. This helps in diagnosing and addressing issues within solar energy systems.

All the gathered data and analysis are integrated into a digital twin model of the building, which is incorporated into the platform developed by SE1. This integration enables users to monitor, analyse, and evaluate the building's condition and energy performance comprehensively, supporting informed decision-making for maintenance and retrofitting strategies.

SE1 and SE2 also foresee the calculation of the proposed KPIs, which are valuable for users as they enable an objective assessment of the quality and accuracy of the captured and processed data, essential for ensuring the reliability of the services provided. Firstly, the percentage of façade that is obstructed by obstacles when capturing drone images, which is calculated by generating a ratio between the captured envelope and the actual envelope. Secondly, the quality of the point cloud, calculating the density of the point cloud by measuring the distance between points. Finally, the noise on the point cloud surfaces, calculating the similarity between the elements obtained with respect to the real ones.

3.2. User experience

3.2.1. Target users

The services support urban stakeholders, including urban planners, policy makers, construction companies, and citizens, by providing valuable insights into the structural and thermal conditions of buildings. This allows for an informed understanding of the current state of buildings, both new and old, and the critical areas requiring attention, such as cracks, humidity, thermal bridges, and malfunctioning solar panels.

Municipalities and regional policy decision-makers can utilize this service to assess thermal conditions of public buildings by leveraging the digital twin's (DT) detailed geometric and thermal models, ensuring that their infrastructure is energy-efficient. By leveraging the service's detection capabilities, they can prioritize renovation projects and promote energy efficiency programs at a municipal or regional level. The ability to detect issues such as cracks or thermal inefficiencies allows them to focus on specific areas requiring investment or repairs. In addition, the integration with EGNSS data ensures that each building is accurately located within city-scale models, making it easier to analyse the city's energy profile.

Companies in the construction sector benefit from the services in two major ways: first, through the identification of buildings in need of renovation, enabling them to approach building owners with data-driven proposals from the semantic-rich digital twin; second, the service also supports quality control during the construction process. This includes monitoring new buildings or recently renovated ones to ensure they meet the required standards, helping companies avoid future costly repairs and ensuring quality assurance. The ability to monitor the progress and detect issues in real-time also enhances their competitiveness and reputation in the market.

Urban planners can use the service to visualize the physical state of buildings in the city in the interactive platform, allowing them to make more strategic urban development decisions. The data on external façades and thermal properties enables them to plan energy-efficient interventions, while the identification of issues like cracks or humidity helps in prioritizing urban renewal projects.

Building and house owners, along with **city residents**, benefit from detailed reports on the condition of their properties, including post-construction quality checks for newly built buildings. The service helps to identify issues such as thermal bridges, cracks, humidity, and inefficiencies, enabling informed decisions on renovations, upgrades, and maintenance planning to improve energy efficiency.

Research groups and academia can use the service as a powerful tool for the digital twin construction and studying building performance over time. By collecting data on various building types, including new constructions, they can develop new strategies for improving energy efficiency and building design. The service's detailed reporting on building envelopes and thermal conditions allows for in-depth research and comparison of various rehabilitation methods or materials.

The complete **user experience** is depicted in the Figure 17 below. The access to the building-scale services platform will occur through the Core Platform.

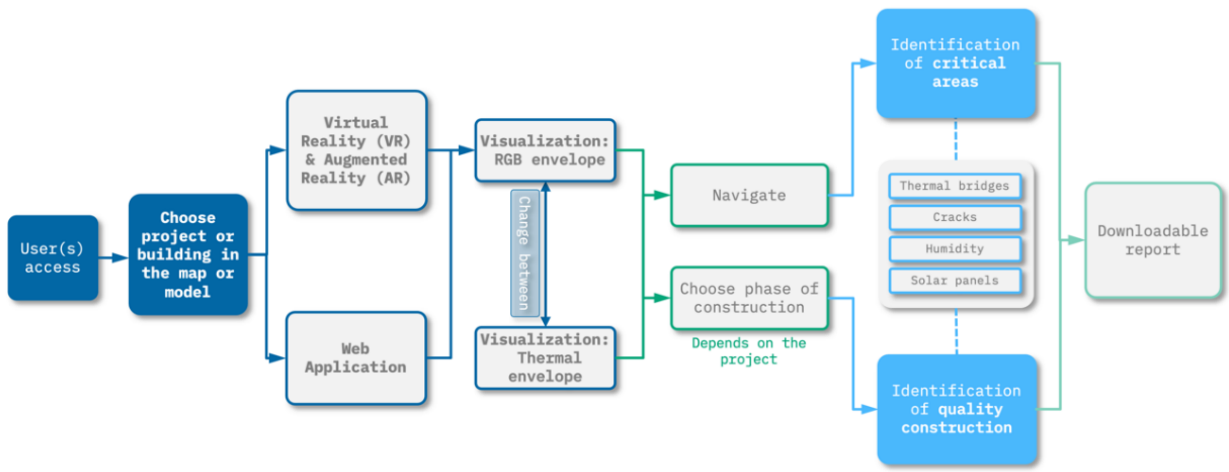


Figure 17. SE1 and SE2 workflow

The building scale services we application will be developed for the third technology release, allowing the visualization of the digital twin together with the enrichment provided by the services.

This platform will allow:

- Visualization through the platform
- Visualization through AR/VR
- Selection of the construction phase (if applicable)
- Activation or deactivation of visualization layers
- Switching between visualization modes (RGB/thermal)
- Viewing or downloading reports
- Tools: zoom, adjust colour scale, select point information, histogram, views, and section.

3.2.2. SE1 visualisation "platform"

For the SE1, we will develop an immersive VR/AR based on Unreal Engine (as shown in Figure 18 and Figure 19, which are examples developed for a road digital twin) to create an integrated executable file (**.exe**) for end-users. This approach provides users with an engaging and interactive environment to visualize and explore digital twin data, point cloud data, and thermal data in a real-time 3D setting.

Key features:

Integrated visualization: The VR/AR solution integrates detailed digital twin models generated from point cloud data and information enriched from SE2. The system uses high-resolution LiDAR-derived point clouds to capture the intricate details of building geometry, and thermal sensors provide data on heat distribution across building surfaces. This data is processed and rendered in Unreal Engine and can be shown under selection to create a realistic, interactive 3D model that users can navigate in real-time.

Immersive interaction and navigation: Users can move freely within the virtual environment, walking through rooms and floors, exploring both the building's interior and exterior spaces (see Figure 20). The ability to physically walk or teleport within the virtual space makes it feel more realistic, allowing users to experience the actual scale and layout of the building. Users can also interact with specific building elements, such as switching between thermal views and structural geometry, to assess performance or identify problem areas like thermal bridges or cracks.

This VR/AR solution is ideal for municipalities, urban planners, and construction companies who want to immerse themselves in building data to make strategic decisions in design, maintenance, or energy-efficiency improvements.

Figure 18. VR/AR solution for other projects

Figure 19. Example tool bar in the visualisation interface

Figure 20. Navigation experience with the VR/AR environment

In parallel to the immersive VR/AR solution, **screen-mode visualization solution** built on an **open-source visualization platform** will be also explored to visualize both IFC (International Foundation Class) data and PCD (point cloud data), as shown in Figure 21). This system is designed for users who prefer a simplified, accessible way to interact with building data without the need for VR or AR hardware. The screen-mode solution provides a comprehensive yet easy-to-use interface, enabling users to visualize and analyse building performance data on standard 2D screens.

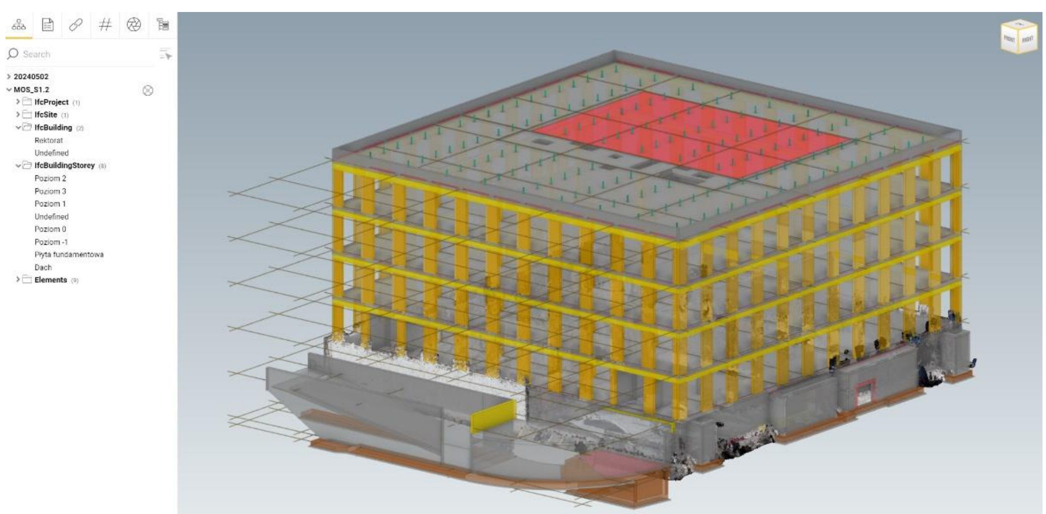


Figure 21. Screen-mode visualisation for IFC and PCD

Key features:

Simplified data display: The screen-mode solution consolidates multiple data sources—digital twin models, point cloud data, and thermal imaging data—into a unified 2D interface. The digital twins are generated from 3D point cloud datasets, while thermal data from SE2 is overlaid to show temperature gradients and areas of inefficiency. Using open-source rendering frameworks, such as Three.js or ParaView, the system provides a highly responsive and detailed visualization of the building environment.

Integrated display and interaction: The screen-mode interface is user-friendly designed and provides a centralized view of relevant data. Users can switch between structural models, thermal maps, and point cloud views to assess different aspects of building performance. The interface includes tools for zooming, panning, and layer toggling, allowing users to focus on specific areas of interest. Additionally, the solution supports report generation, enabling users to export detailed insights for further analysis or presentations.

Targeted for presentations and quick assessments: This mode is ideal for municipal decision-makers, building owners, and researchers who need a direct, easy-to-navigate interface for quick assessments or presentations. The open-source visualization framework allows users to view the building's performance at a glance, identifying issues such as cracks, humidity, or thermal inefficiencies.

3.2.1. SE2 visualisation "platform"

For SE2, a simulated application has been created to illustrate its intended functionalities, as shown in following figures (Figure 22 to Figure 43). While this simulation may differ from the final version, which will be developed collaboratively with SE2, it effectively demonstrates comparable features, though the visual interface may vary. At the time of this deliverable, the platform for both services is under development and this is provided here for demonstration purposes only.

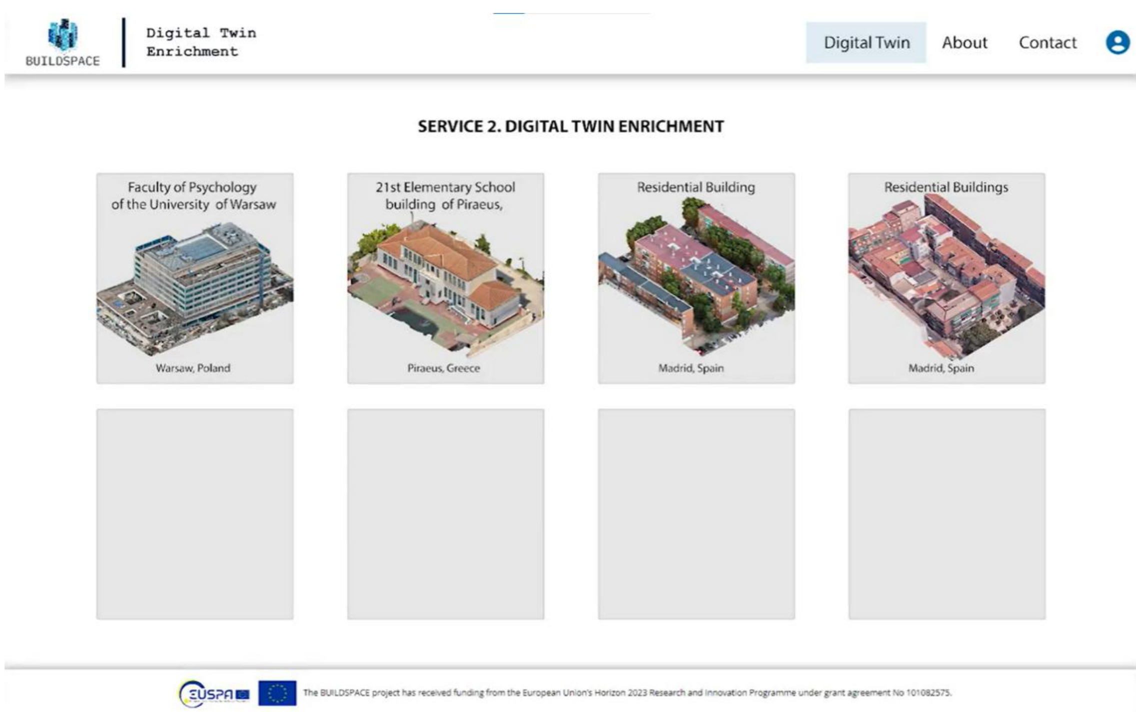


Figure 22. SE2 visualisation main menu

When accessing the service, a menu will appear to select the pilot or building of interest (Figure 22).

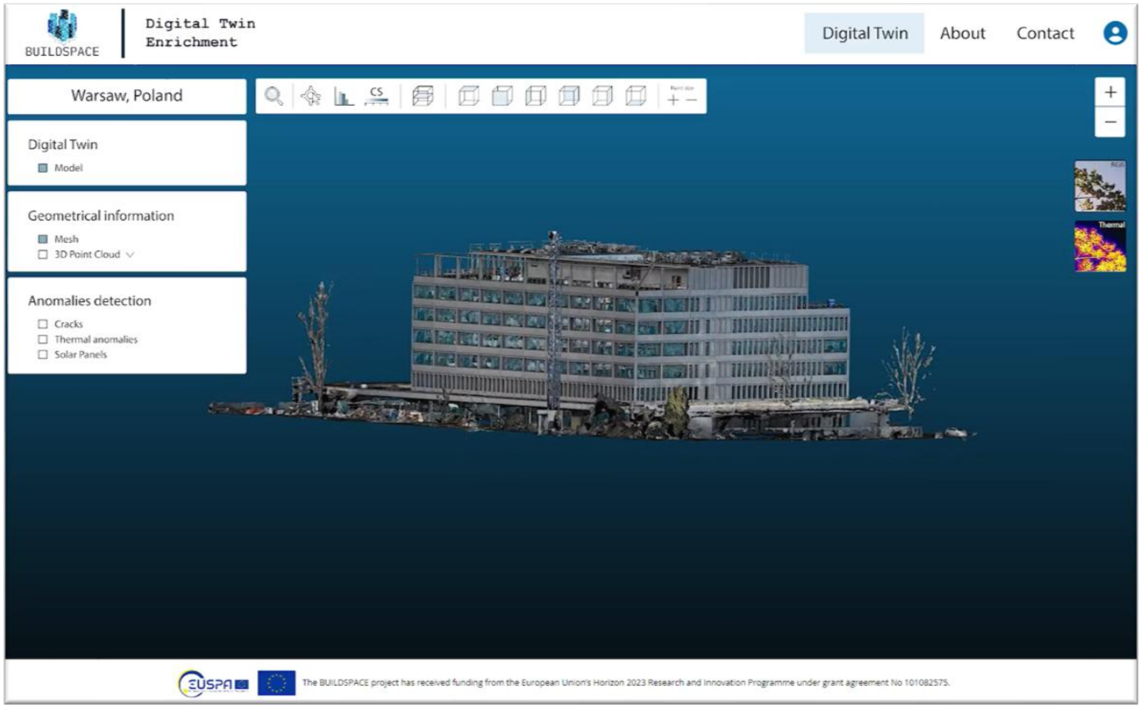
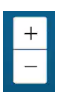
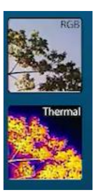


Figure 23. RGB mesh displayed and functionalities

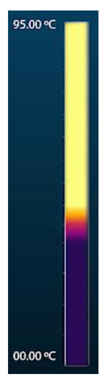
On the screen, the user can navigate and explore different utilities or toolbars (Figure 23). On the right side, find the following ones:



- Zoom: Zoom in or out on the model.



- Switch from RGB to thermography: Change the visualization mode.



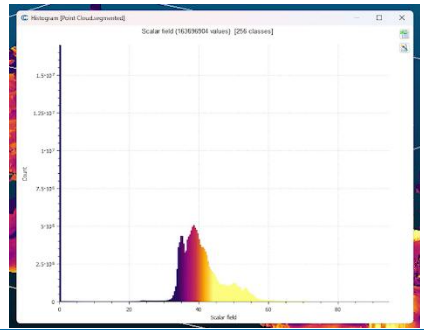
- Legend: When thermography is activated, the corresponding colour legend appears.

At the top, there is a toolbar with functionalities related to the model:

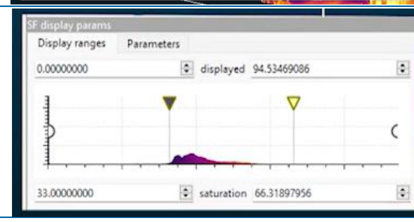
- Magnifier: Returns to a general view of the model.

- Point information: Clicking on points in the cloud provides information with corresponding metadata, in this case, temperature (scalar field) and coordinates.

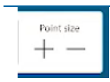
- Histogram: Generates a graph showing the relationship between the number of points and their temperature.



- Colour Scale: Allows changing the colour scale of the thermography to adjust it to the area of interest in the model.

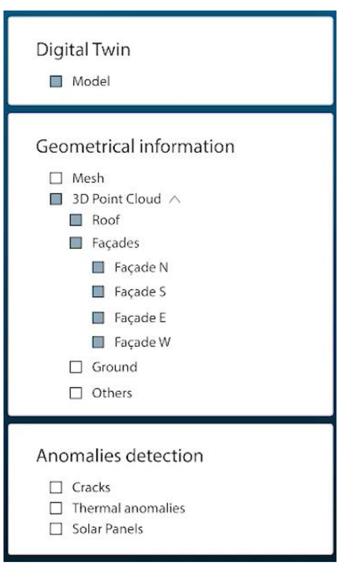


- Section: Allows cropping the viewing area.
- Views: Change of view (top, bottom, sides, front or back).

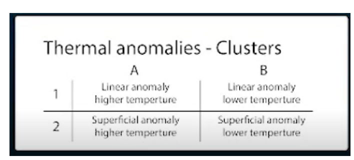


- Point size: Change the point size in the cloud.

On the left side of the screen, we find a layer selector:



- **Digital Twin**:
  - Model related to the model developed by SE1.
- **Geometrical information**:
  - Mesh with texture from the drone flight image capture.
  - Point cloud obtained from the drone flight image capture, segmented and classified.
- **Anomalies detection**:
  - Cracks detection of cracks in the envelope
  - Detection of thermal anomalies in the envelope
  - Detection of malfunctioning cells in solar panels



Thermal anomalies - Clusters

	A	B
1	Linear anomaly higher temperture	Linear anomaly lower temperture
2	Superficial anomaly higher temperture	Superficial anomaly lower temperture

The following figures (Figure 24 to Figure 43) show the visualisation of SE2 different elements and functions as explained.

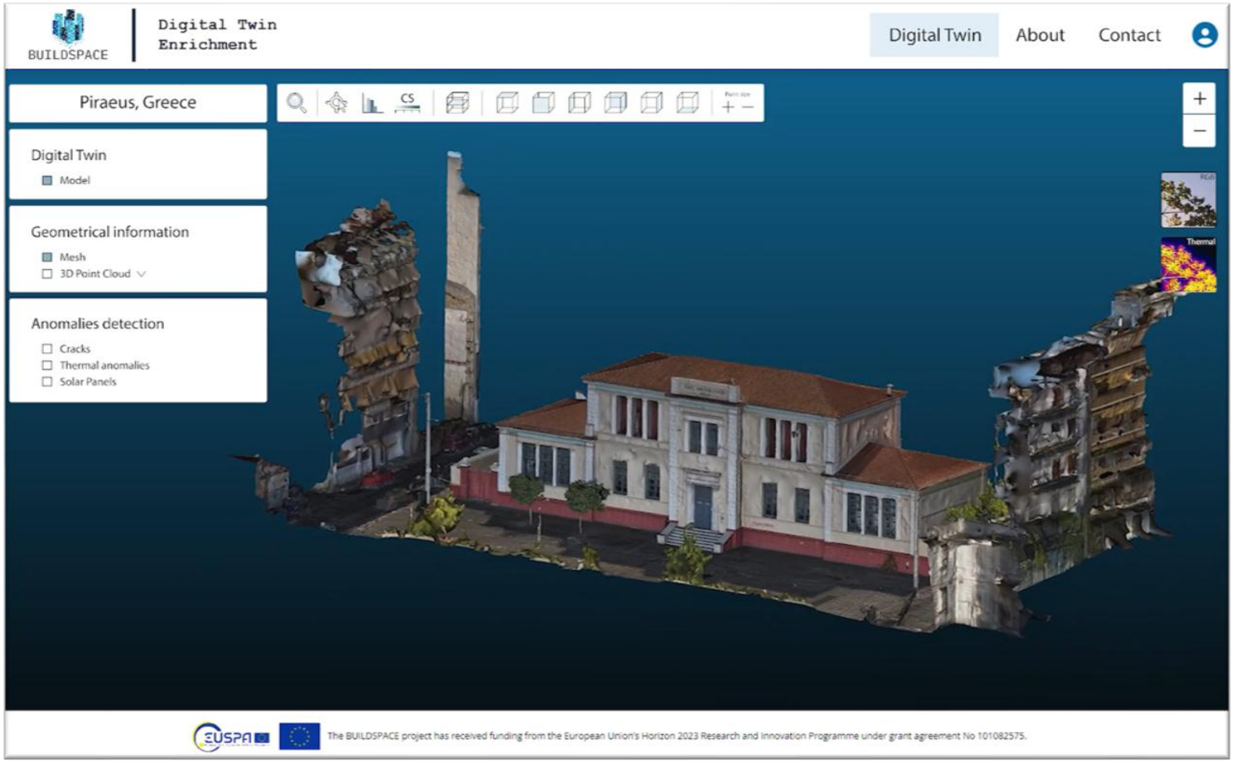


Figure 24. RGB mesh

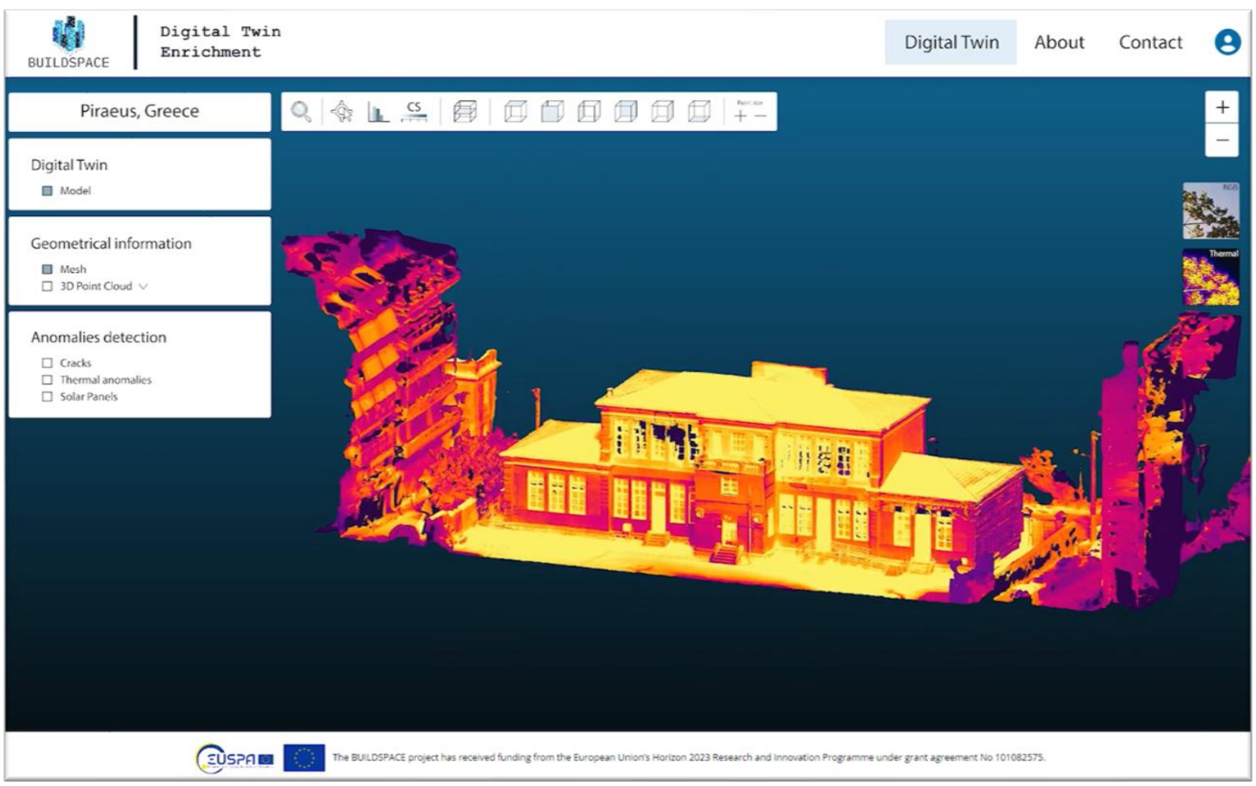


Figure 25. Thermal mesh

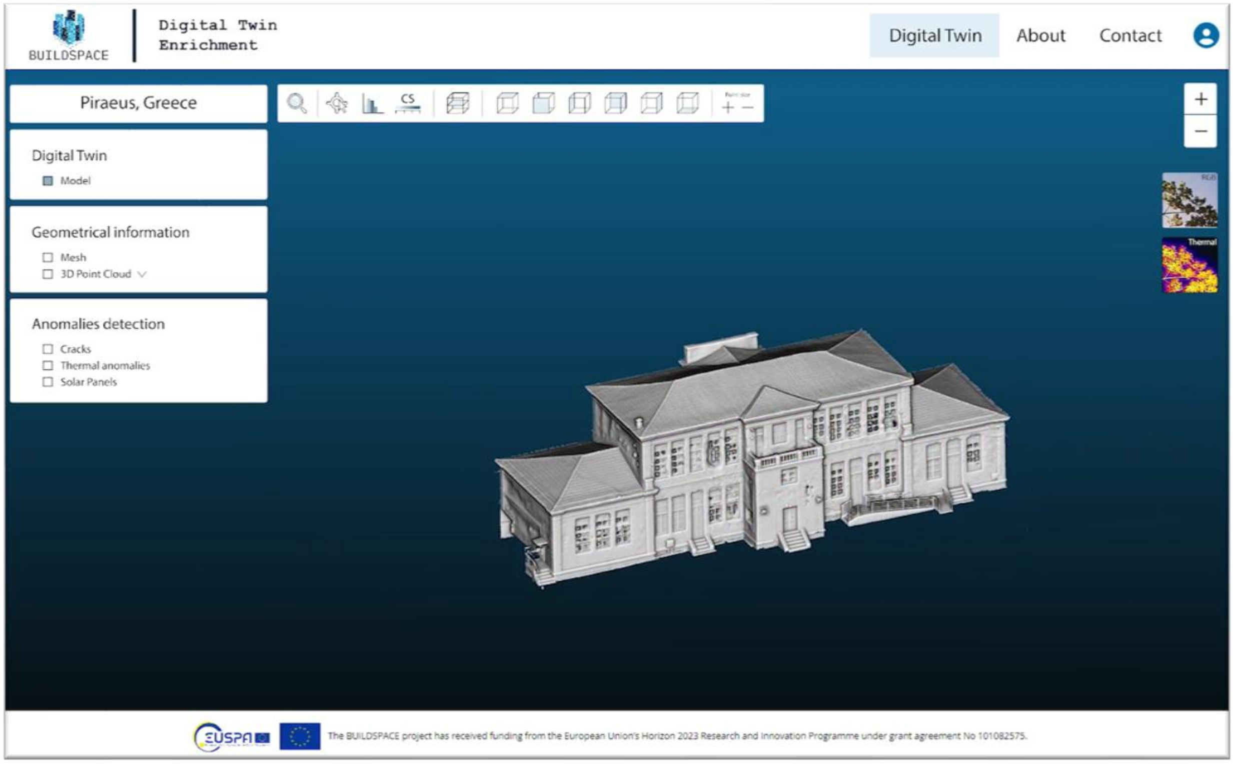


Figure 26. No texture mesh

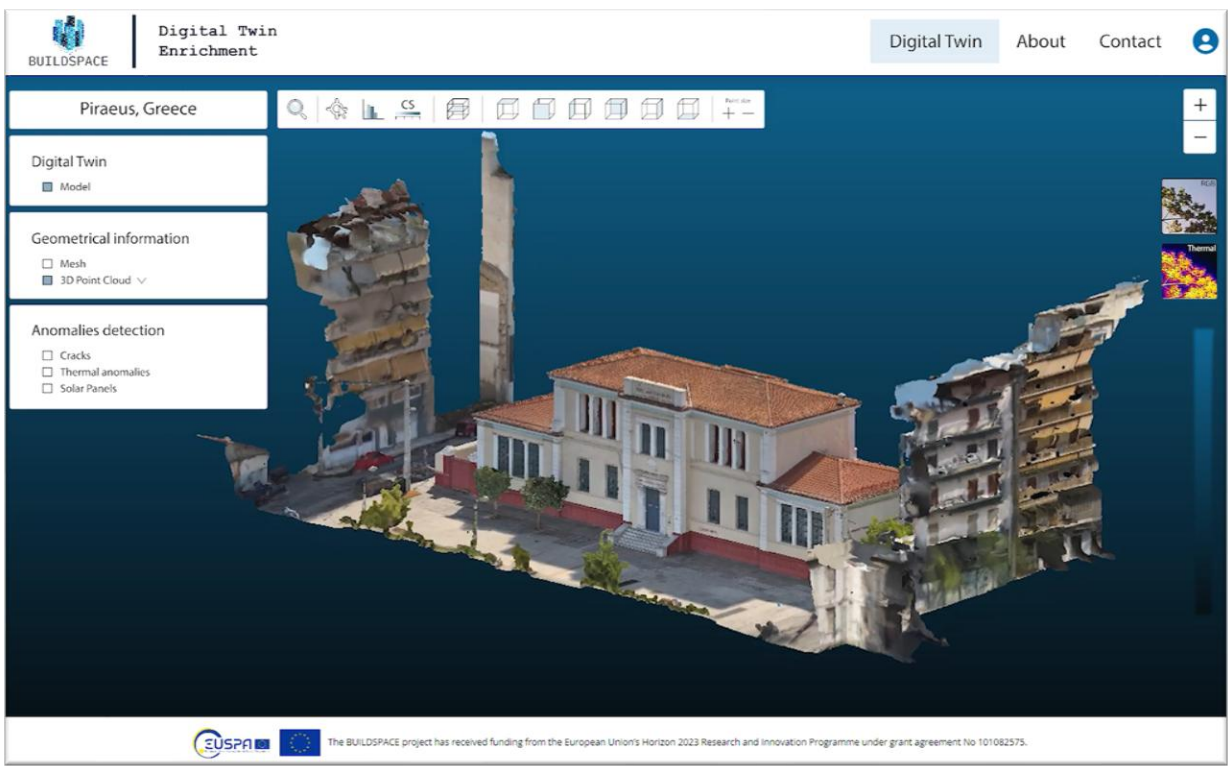


Figure 27. RGB point cloud

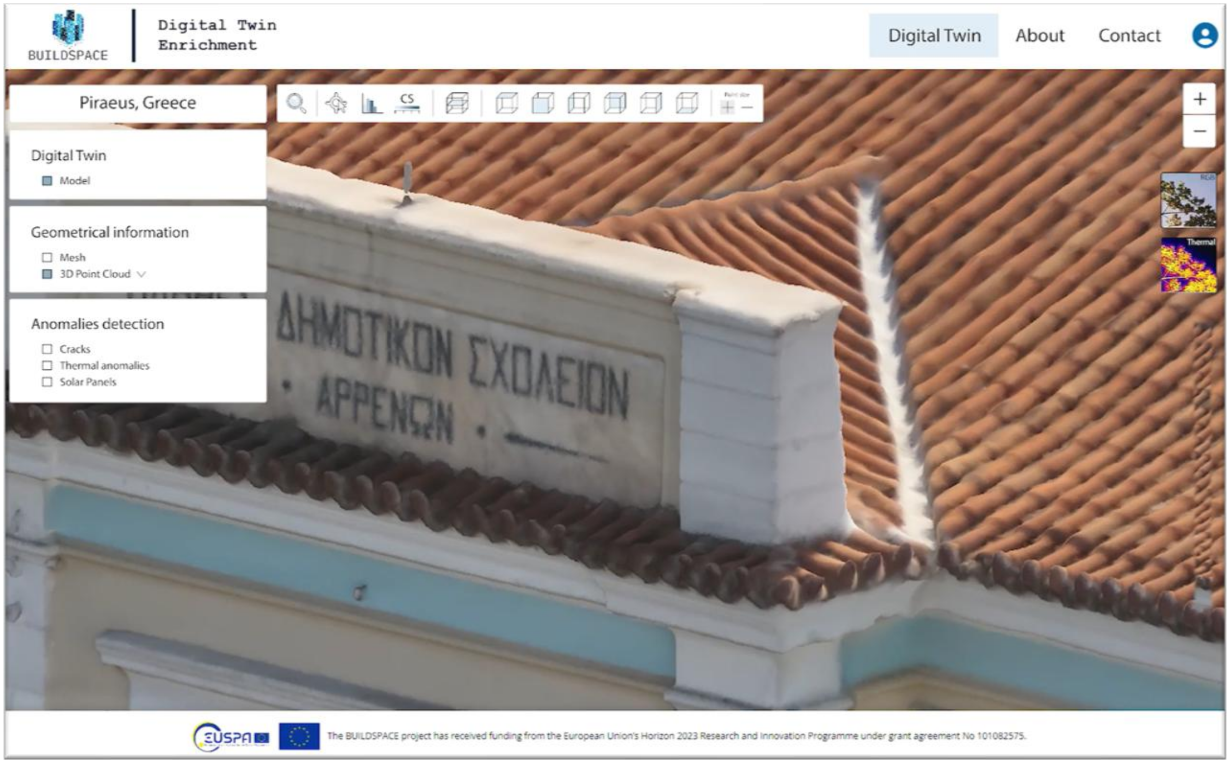


Figure 28. Change point size

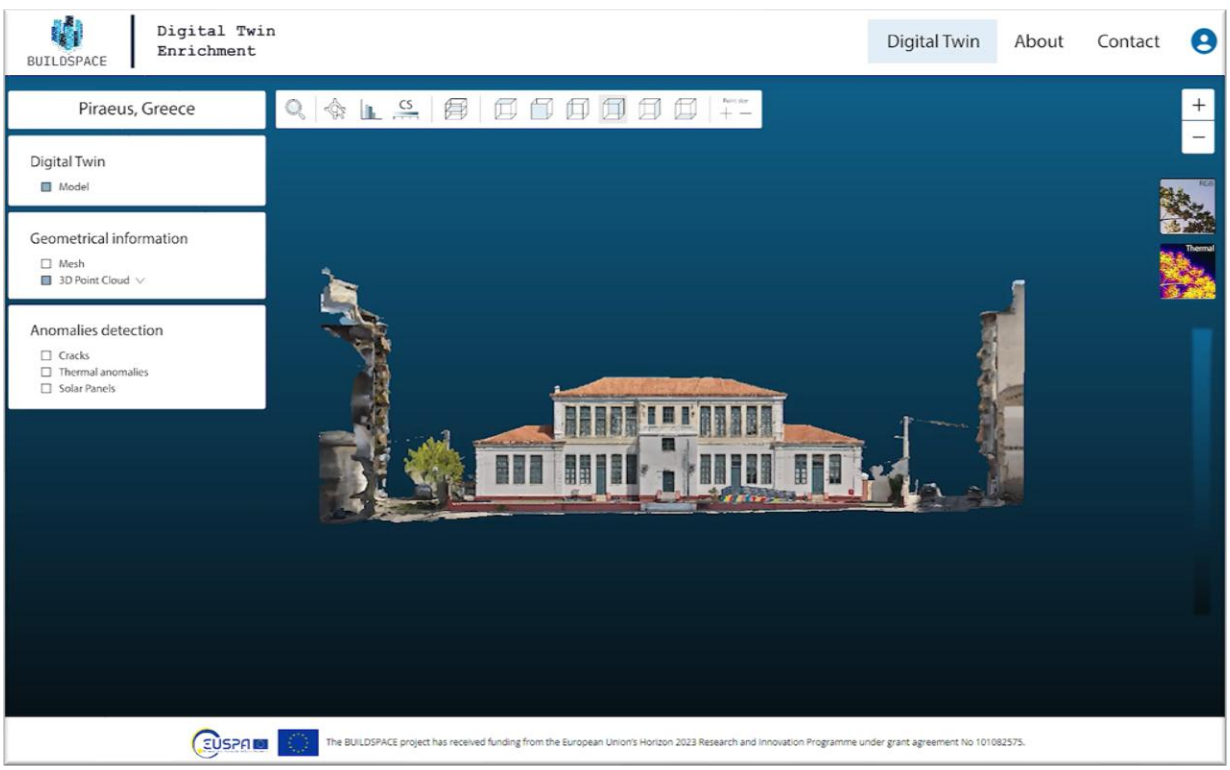


Figure 29. Change view

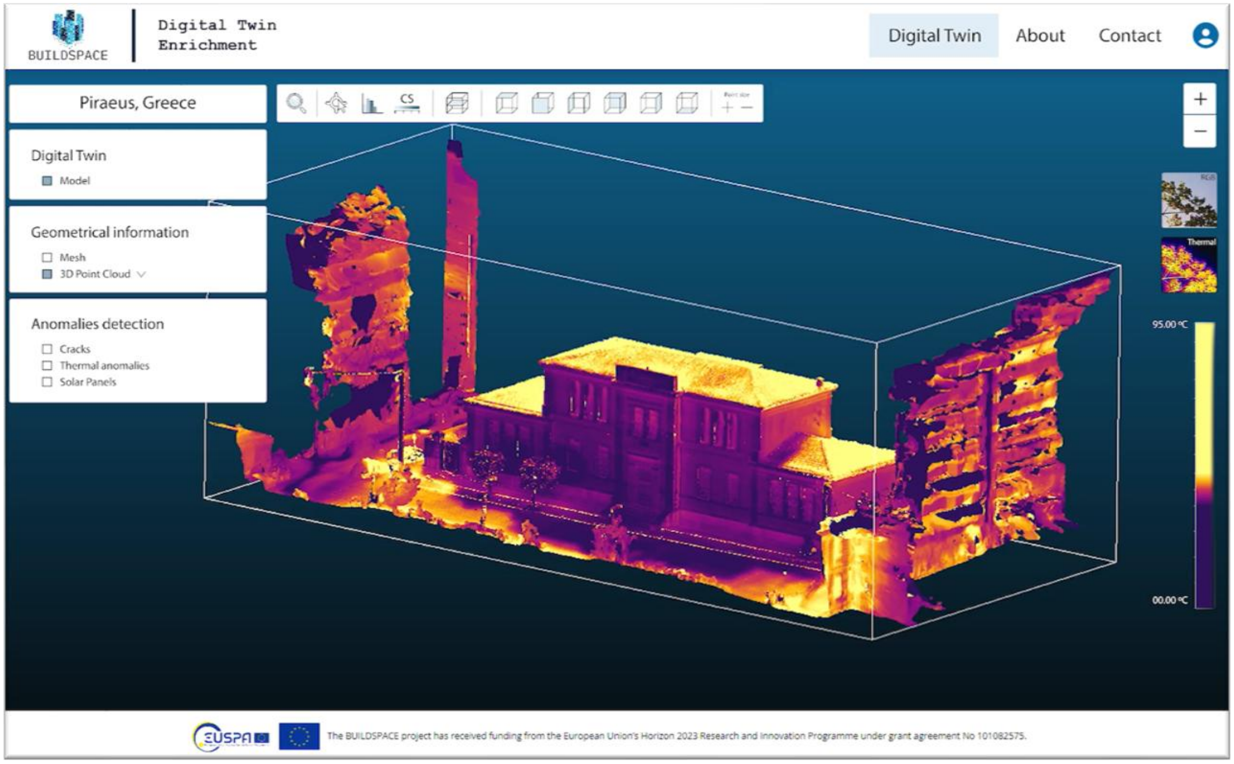


Figure 30. Thermal point cloud

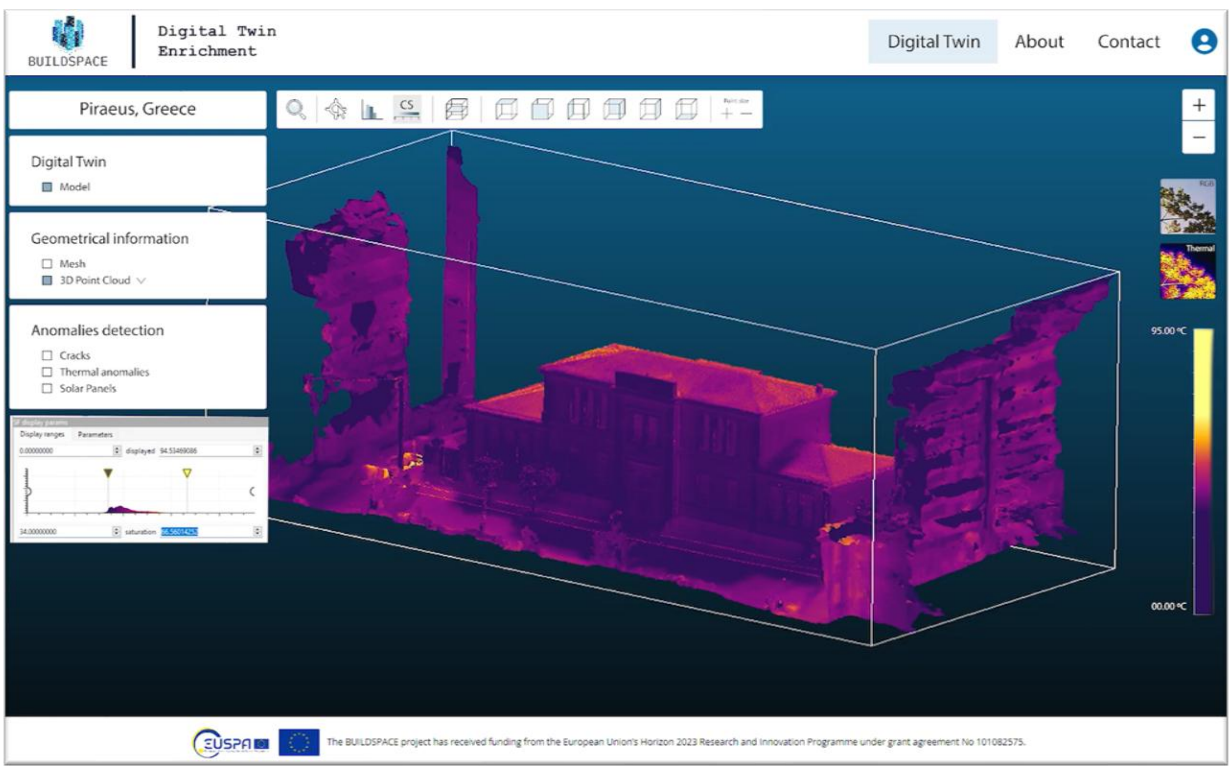


Figure 31. Change colour scale

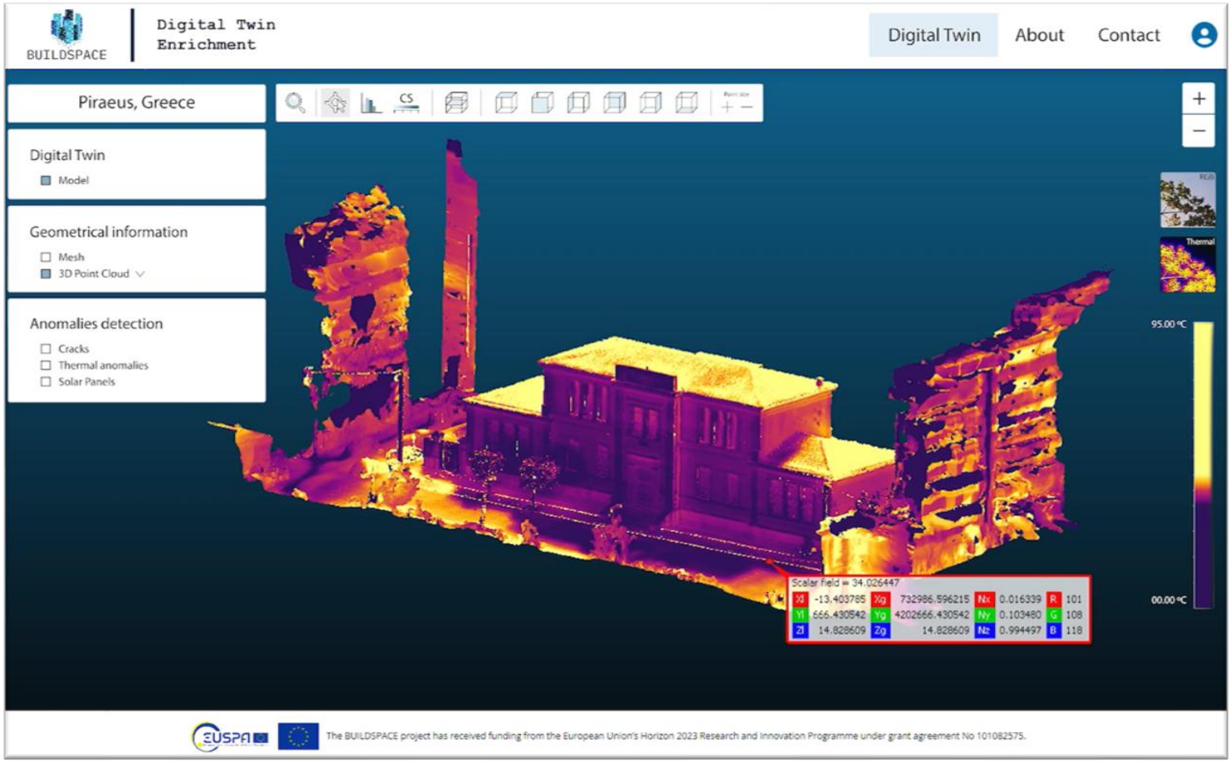


Figure 32. Point information

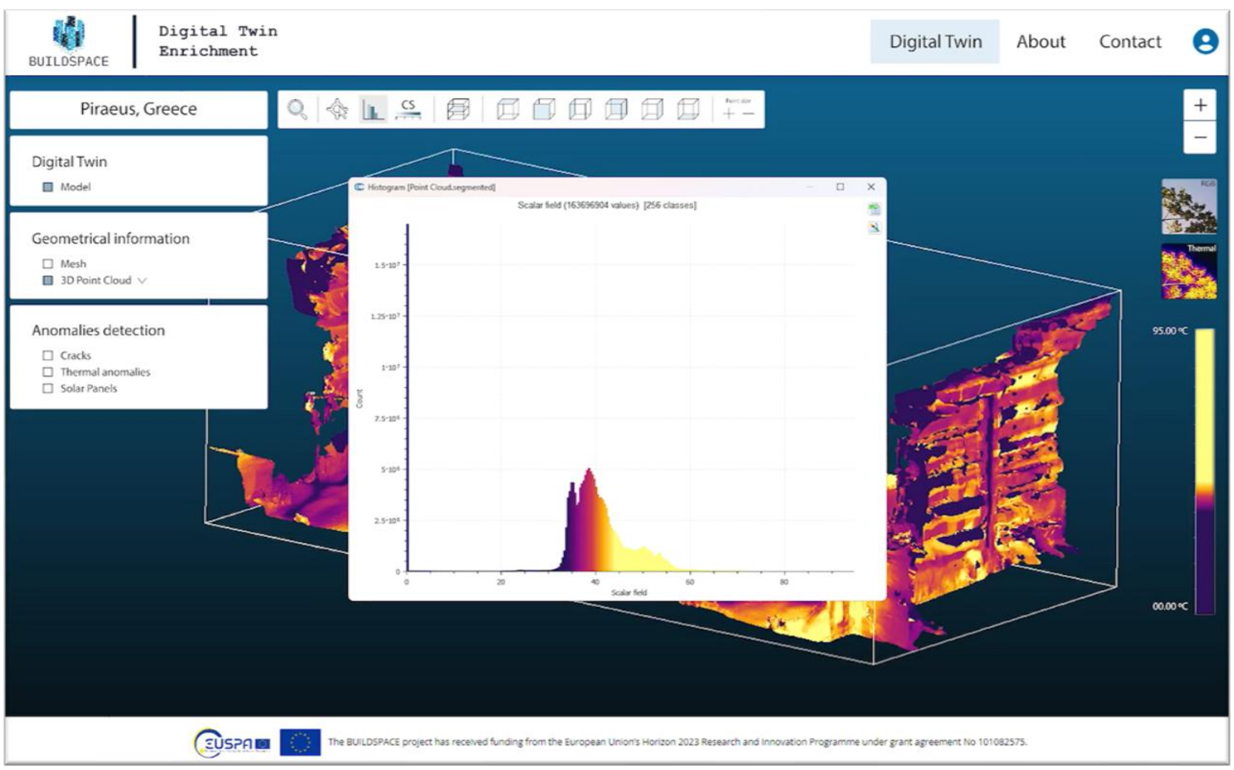


Figure 33. Histogram

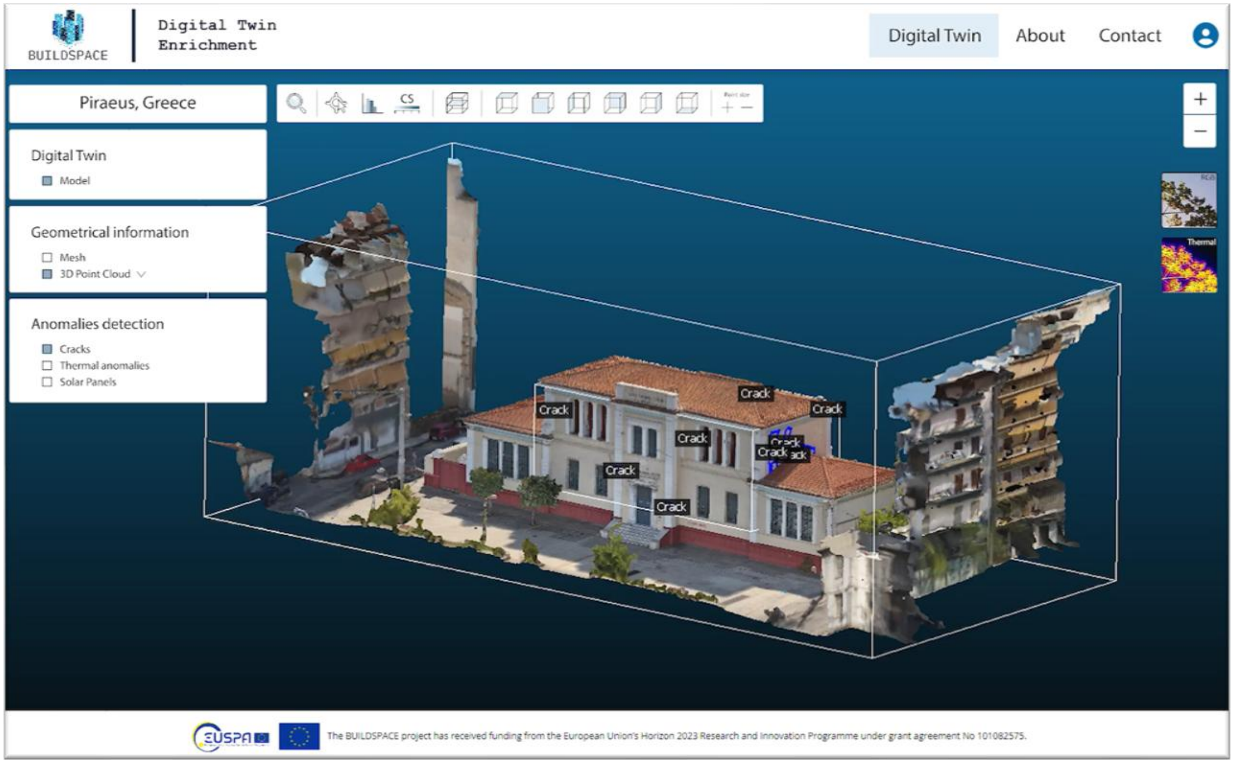


Figure 34. Cracks detection

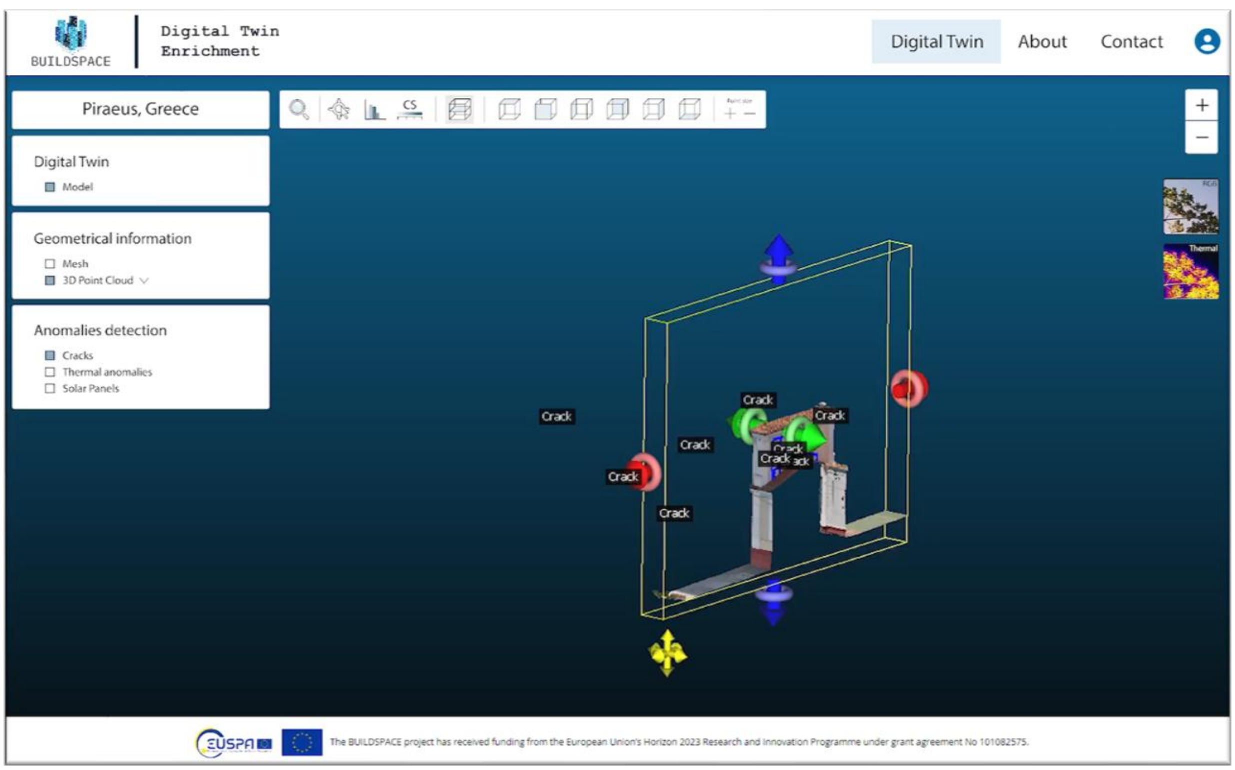


Figure 35. Section

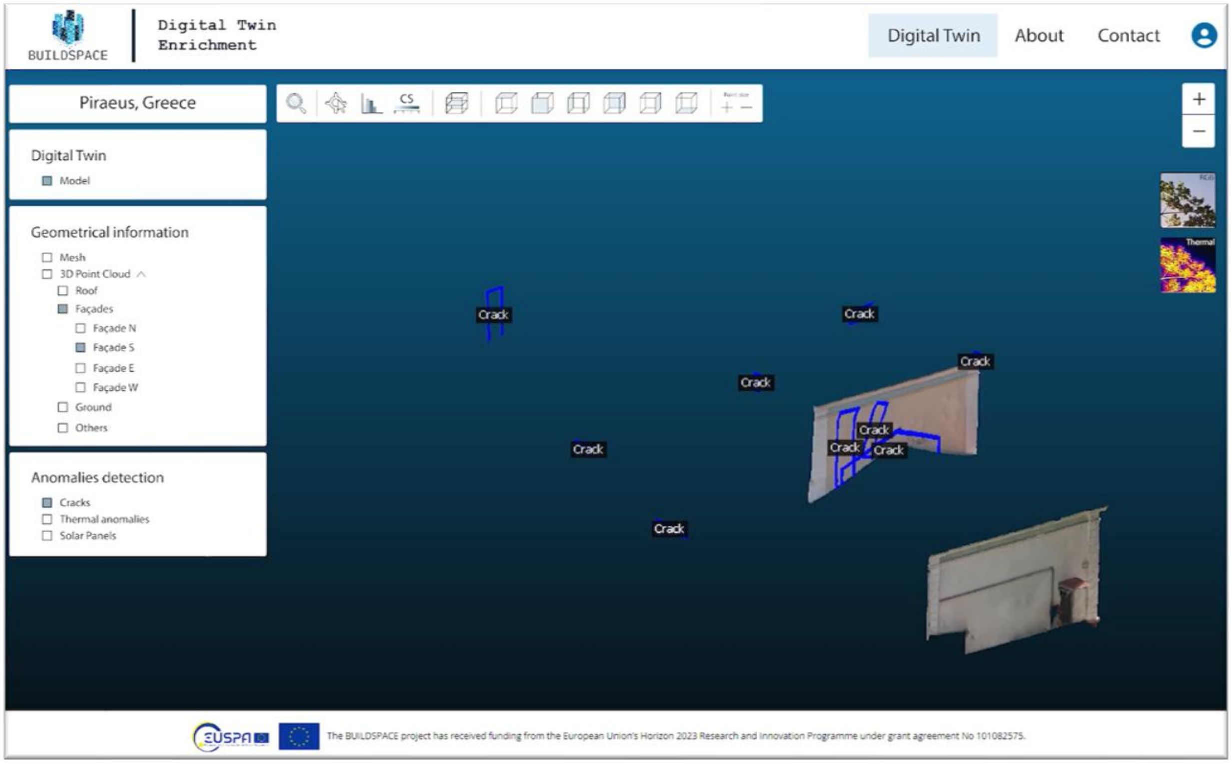


Figure 36. Classification of façade

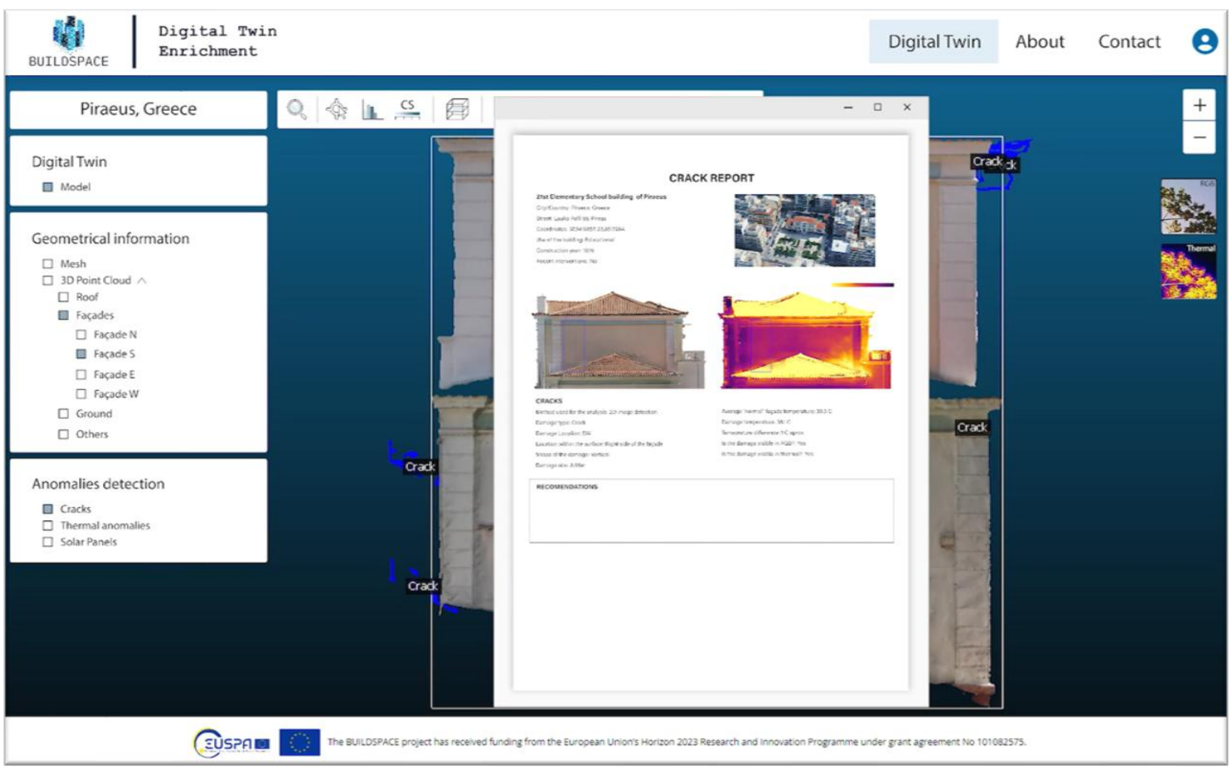


Figure 37. Crack report

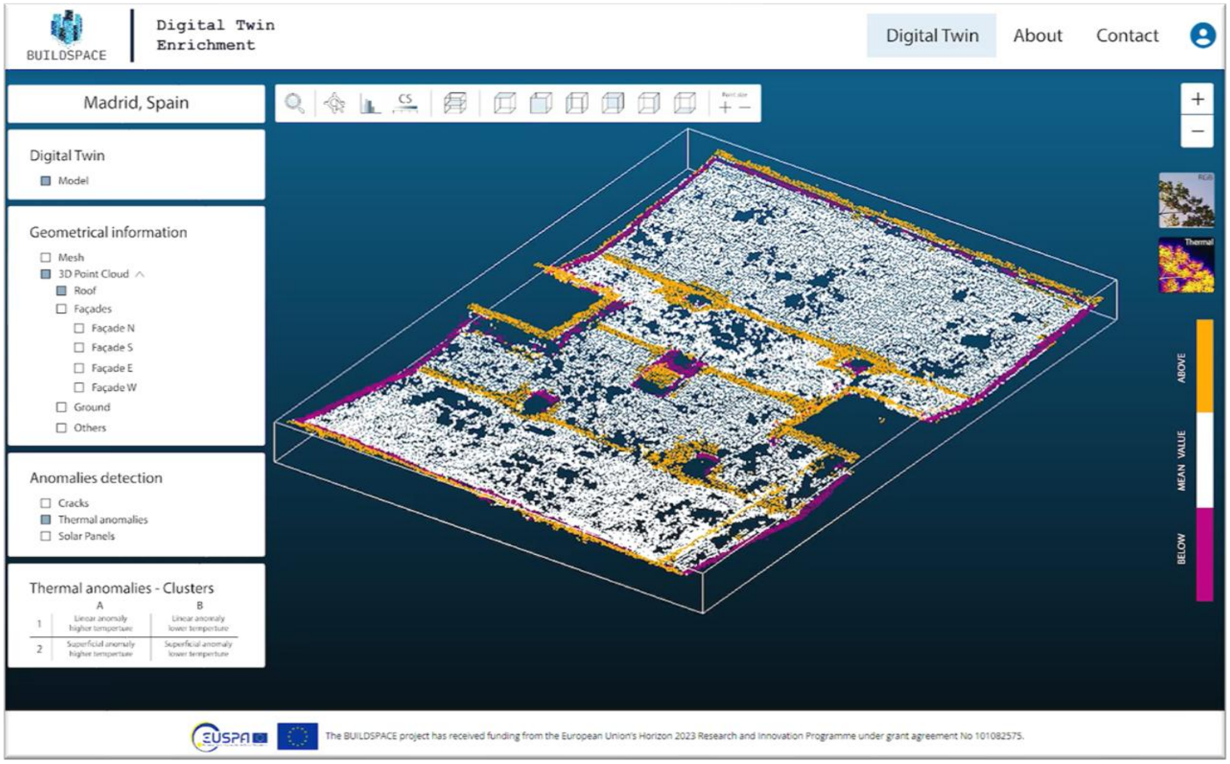


Figure 38. Thermal anomalies detection

Figure 39. Clustering (thermal anomalies detection)

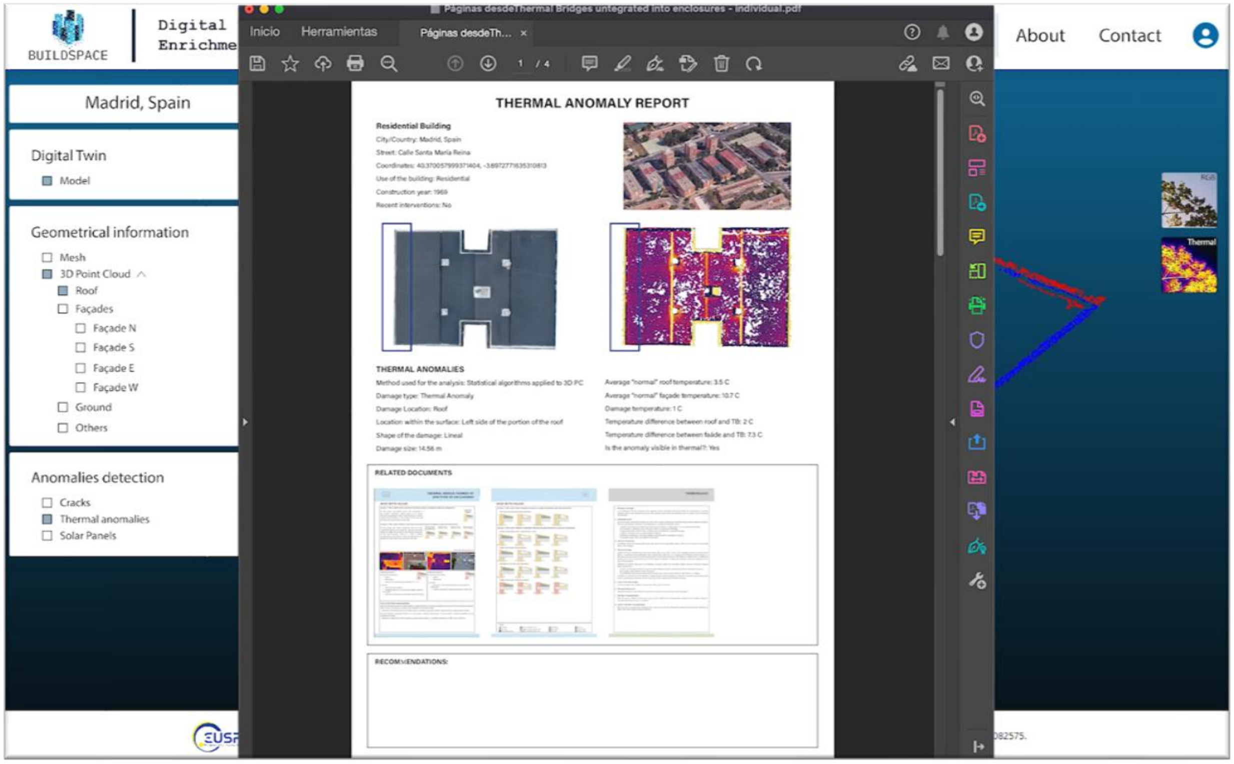


Figure 40. Thermal anomalies report

Figure 41. RGB Solar panels

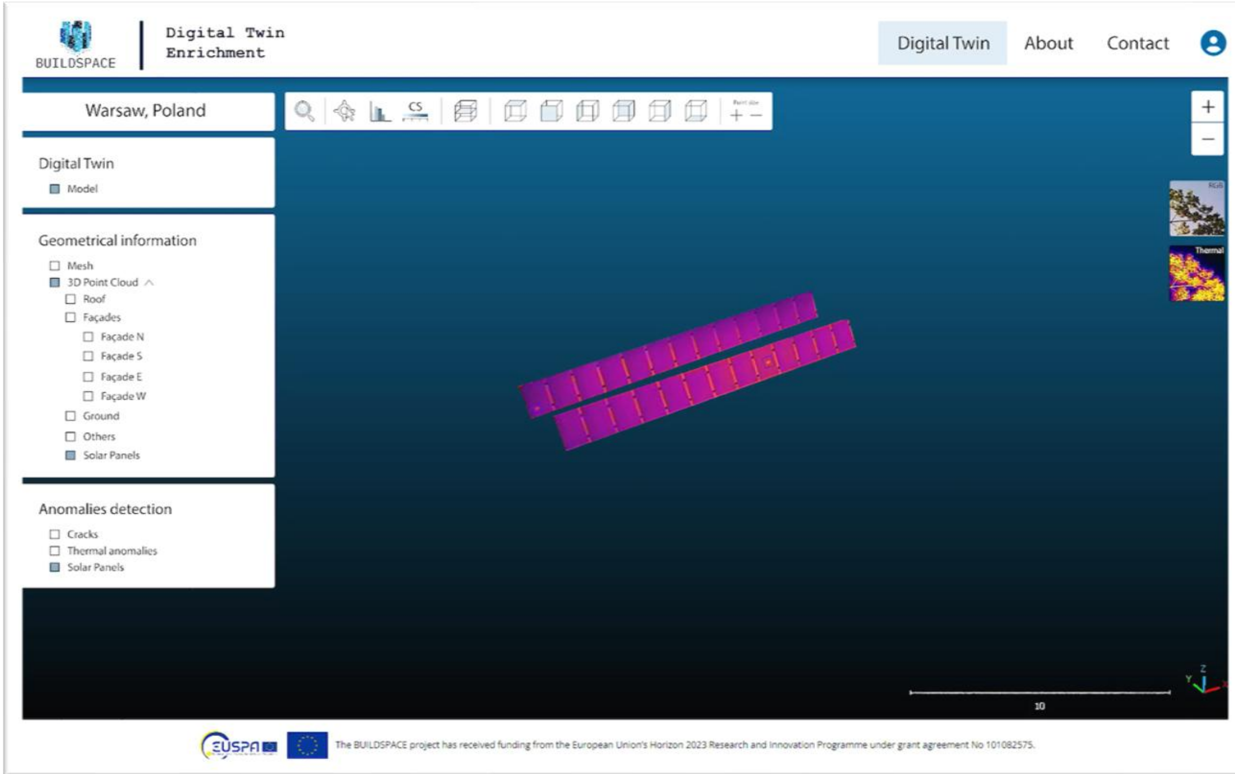


Figure 42. Thermal. Solar panels detection

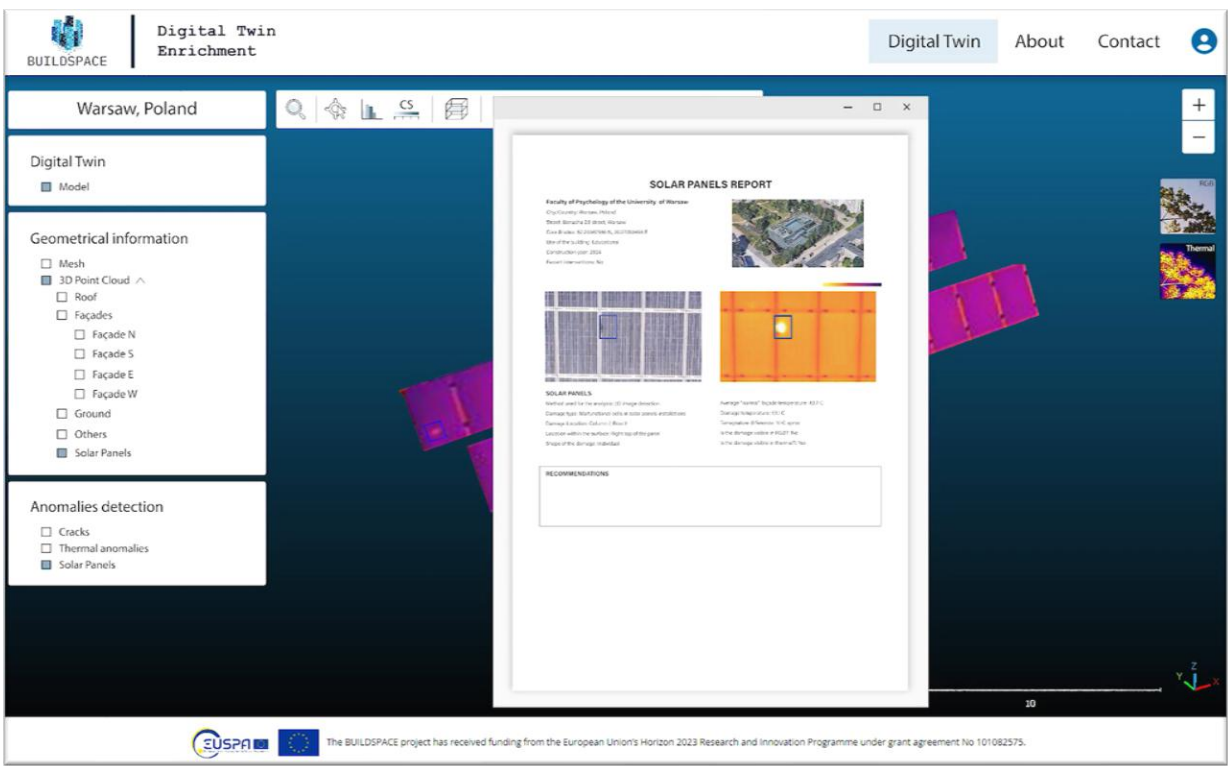


Figure 43. Solar panels report

3.3. Application to pilot and replication potential

3.3.1. SE1. Pilots

There are four pilot cases involved in SE1, the videos of the generated/updated digital twin are uploaded HERE. The target of digital twin generation is shown as below (Table 3).

Table 3. Pilot cases of Digital Twin Generation (SE1) and target

Pilot	Area/ Target
1 – MOS	Multiple scans during the construction progress & façade and indoor environment DT generation
2 – RPR	Façade
3 – MOP	Façade
4 – IMZI	Façade

In the Polish pilot, two distinct tasks are being carried out:

1. Façade and indoor environment DT generation: This will include the creation of detailed DTs for both the external façade and indoor spaces.
2. Digital twin updates during construction: This involves continuous updates of the DT by comparing the point cloud data (PCD) with the as-designed 4D BIM model, enriched with construction scheduling information. This process ensures that the DT reflects real-time progress and accurately represents the construction stage.

For pilot 3 (Piraeus, Greece) and pilot 4 (Ljubljana, Slovenia), the DT generation will follow similar methodologies, particularly in processing the PCD, applying computer vision techniques, and generating IFC models. These pilots will also involve capturing the façade data and converting it into usable formats for further analysis and integration.

In the final pilot in Riga, Latvia, the focus is on façade data collected from terrestrial and airborne laser scanners. Due to the nature of these methods, the point cloud data has a lower density compared to other pilots. To address this, the point cloud will be processed into .obj format and then converted to IFC format. This ensures consistency in data structure and format across all pilots.

Further technical details are elaborated in next section 3.4.1.

The algorithms developed for the SE1 pilots will be delivered as part of the project's output, providing a customised solution for the generation and updating of digital twins. These algorithms serve as a core foundation for the replication of this service across different buildings and projects. However, due to the variety of pilot cases involved, it is challenging to create a single, fully integrated solution that applies seamlessly to all scenarios. Each pilot case requires specific adaptations depending on the building type, data density, and environmental factors.

Replication in similar building types: The workflow and data processing pipeline developed in this project can be replicated in buildings that share similar data collection methods and have comparable architectural styles. For instance, the methods applied in the façade pilots can be reused in buildings with similar structural features, in the case the data is captured using the same point cloud and laser scanning techniques. The IFC generation process, which translates point cloud data into structured digital twin models, can be easily transferred across different projects with minimal adjustments.

Construction case replication: For the construction case (Pilot 1 – Poland), the approach to real-time digital twin updates by comparing 4D BIM models with as-built data captured through drones and point cloud scans can be applied to a wide range of construction projects. The algorithms and workflow designed for construction-related DT updates are flexible enough to be adapted to different project types.

While there are some limitations in providing a one-size-fits-all solution, the modular nature of the workflow ensures that it can be replicated and customized to meet the needs of different projects, particularly in cases where the same data collection methods and similar building structures are involved.

3.3.1. SE2. Pilots

The Digital Twin Enrichment (SE2) service is currently being piloted in two distinct environments: a school in Greece and a newly constructed university building in Poland. These pilot projects are crucial for assessing the service's functionality and its potential for wider application.

In Greece, the service focuses on evaluating the thermal envelope of an existing school building to determine its condition for potential rehabilitation or renovation. This involves capturing external images to analyse the current state of the thermal envelope and detecting thermal anomalies or issues that may need attention.

In contrast, in Poland, the service is applied to a newly constructed university building to assess the quality of the construction. This includes evaluating the building's thermal performance. The collected data could help identify discrepancies between the proposed design and the actual construction, allowing for the assessment of any construction errors or deviations.

The enrichment provides several functionalities. It offers 3D visualizations of both RGB and thermal data captured during UAV flights. This feature could facilitate monitoring different phases of construction for new buildings or tracking changes over time for existing ones. Additionally, it includes detailed interior views to assess internal structure and condition.

The service also includes solar panel monitoring, which identifies and evaluates the performance of solar panels, detecting any malfunctioning units. This functionality could enable periodic assessments to ensure optimal operation of solar installations. Furthermore, SE2 utilizes AI support to detect and analyse critical areas in the building envelope, such as cracks, moisture, and thermal bridges. Cracks are identified through RGB imagery and classified by their orientation and position on the façade, while moisture and thermal bridges are detected as thermal anomalies using statistical and algorithmic methods.

Comprehensive downloadable reports are generated for detected anomalies and critical areas, providing detailed insights and recommendations for intervention. These reports aid in decision-making related to building maintenance and renovation.

The potential for replicating is considerable. The service can be adapted to various building typologies (building requirements added in the *Annex A – Digital Twin Recommendations* of the D3.1) and cities worldwide. Future developments may include automating UAV flights, allowing for planned captures of individual buildings or entire city blocks. The integration of critical area detection software could enable automatic identification of issues such as humidity, thermal bridges, cracks, and malfunctioning solar panels. Each detected issue could be documented in downloadable reports, enhancing the efficiency of building evaluations.

This capability will facilitate the assessment of building conditions across cities, generating comprehensive 3D meshes or point clouds (both RGB and thermal) with detailed temperature and damage information. The insights gained from these pilots will be essential for optimizing SE2, expanding its functionality, and applying it to a broader range of building types and regions. This makes SE2 a valuable tool for building management, maintenance, and renovation efforts on a global scale.

3.4. Technical development update: second technology release

3.4.1. SE1. Digital Twin Generation

This section introduces the core technical solutions implemented across the four pilot cases in SE1. These solutions are tailored to address various stages of gDT generation, opening detection, data processing, and visualization for each pilot.

Each of the pilots target different aspects of building DT generation, including PCD processing, opening (i.e. doors and windows) detection using both PCD and image-based methods, DT generation and updates, and interactive visualization. While the primary methodologies are consistent across pilots, certain techniques are specifically tested or emphasized based on the unique requirements of each case.

For example, in pilot 1 (Poland), the focus is on multiple scans during construction progress, allowing for PCD-based opening detection and real-time DT updates. Similarly, pilots 2 (Riga, Latvia), 3 (Ljubljana, Slovenia) and 4 (Piraeus, Greece) concentrate on façade data processing, with tailored workflows for each location. Table 4 summarises how each technical solution is applied across the pilots, highlighting key methods such as interactive visualization and opening detection. Detailed explanations of the algorithms and workflows used in each pilot case are provided in the following sections, demonstrating the application of advanced technology to enable precise and efficient digital twin generation. Visualisation for different building environments will be included in the next technical release, with the corresponding code accessible via this LINK.

Table 4. DT solutions (services 1 and 2) applied to the different pilots

Solution	Pilot 1 – Poland	Pilot 2 – Riga	Pilot 3 – Piraeus	Pilot 4 – Ljubljana
PCD processing				
Opening detection (PCD_based)	test			
Opening detection (image_based)				
DT generation				
DT updates				
Interactive visualisation				
Visualisation				

The different techniques are explained more in detail in the following sections.

PCD PROCESSING

The **PCD processing** method is implemented in **Python** using the **Open3D** library and focuses on preparing and extracting structural information from point cloud datasets (Figure 44). This processed data is essential for generating **digital twins (DTs)**. Below is a detailed explanation of each step, with key coding elements included to emphasize the technical aspects.

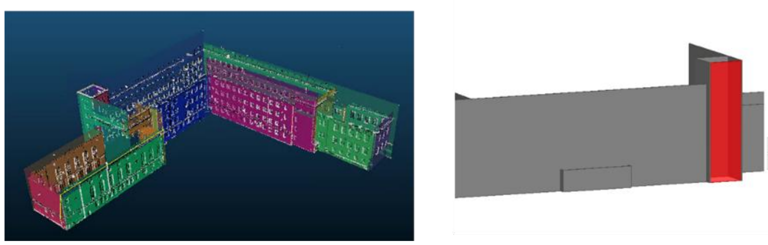


Figure 44. Planar detection to generate the IFC element – RPR pilot

1. Loading point cloud data: The first step involves reading the PLY file (which contains the point cloud data) using Open3D. This code loads the point cloud from a PLY file and converts the points into a numpy array for easier manipulation. The point cloud represents the 3D geometry of a building or façade.
2. Down-sampling: To reduce the computational processing cost, the point cloud is **down-sampled** by selecting every 10th point: every 10th point in the array is selected (`points[::10]`), which significantly reduces the size of the dataset as the other 9 are deleted. This step is critical for large datasets where full-resolution processing is unnecessary or too resource-intensive.

3. Plane segmentation using RANSAC**:** One of the most important tasks in point cloud processing is detecting planes, such as walls or floors. The **RANSAC** algorithm is used here for **plane segmentation**:

```
plane_model, inliers = cloud.segment_plane(distance_threshold=0.0001,
                                           ransac_n=3,
                                           num_iterations=2000)
```

- *distance_threshold*: This defines how close points need to be to a plane to be considered inliers. A smaller value ensures a more precise fit.
- *ransac_n=3*: This specifies that a plane is defined by three points.
- *num_iterations*: The number of RANSAC iterations used to refine the model.

Once the planes are detected, the inlier points are extracted, and the identified plane is saved as a separate **PLY file**. Each iteration detects a new plane, and the **normal vector** of each plane is stored for future analysis.

4. Fitting a vertical plane using boundary points. Once a plane (e.g., a façade) is segmented, it is necessary to fit a vertical plane to extract the geometric information of the **boundary of the façade** using points from the point cloud. This is done by randomly selecting two points and calculating a plane:

```
point1 = points[random_indices[0]]
point2 = points[random_indices[1]]
normal_vector = np.array([-(y2 - y1), x2 - x1, 0])  # Normal vector for a vertical plane
a, b, _ = normal_vector
d = a * x1 + b * y1  # Equation of the plane
```

The calculated normal vector ensures that the plane is **vertical**, and the plane equation `ax + by = d` is derived from the two selected points.

To ensure the plane fits within the **bounding box** of the point cloud, the x and y coordinates are adjusted, and new plane points are created:

```
for z in [min_bound[2], max_bound[2]]:
   y_vals = [min_bound[1], max_bound[1]]
   for y in y_vals:
      x = (d - b * y) / a  # Solve for x based on the plane equation
      plane_points.append([x, y, z])
```

These points are then saved as a **PLY file** representing the fitted vertical plane:

```
plane_cloud = o3d.geometry.PointCloud()
plane_cloud.points = o3d.utility.Vector3dVector(plane_points)
o3d.io.write_point_cloud(output_plane_ply, plane_cloud)
```

To facilitate further processing or integration into other workflows, the final set of plane points is exported as a **TXT file**.

OPENING DETECTION

PCD_based opening detection: this method is designed to handle various point cloud operations, such as downsampling, segmentation, line detection, 2D projection, and window/door detection. It uses the **Point Cloud Library (PCL)** for handling point clouds and **Computational Geometry Algorithms Library (CGAL)** for geometrical operations like convex hulls and polygon generation.

The project consists of the following core files:

1. **workshop_main.cpp (main application)**: This is the main logic file where the entire process of point cloud manipulation, line detection, and polygon handling is executed. It integrates the PCL library to process point clouds and CGAL for polygon generation. The file outlines several main functions that handle different tasks:

    - **mainallsteps()**: This function performs the entire workflow, including reading point clouds from PLY or PCD files, down-sampling, projecting 3D points onto a 2D plane, applying voxel filtering (down-sampling technique to reduce the number of points in a point cloud while retaining its essential geometric structure), detecting lines and planes, and finally writing the results to output files. The code integrates RANSAC for robust line fitting and segmentation.
    - **maincircleransac()**: A variant of RANSAC is used to detect circular structures in point clouds.
    - **mainproject2d()**: Projects 3D points onto a 2D plane to prepare for line and polygon detection.
    - **mainwid()**: A function dedicated to detecting windows and doors based on predefined wall geometry and point cloud data.
    - **mainransacline()**: Detects 2D lines using RANSAC-based segmentation for point clouds.

    These functions are central to the overall workflow of detecting and analysing geometrical features within point clouds.

2. **seedsGenerating.h (class declaration)**: This header file declares the seedsGenerating class, which includes various functions related to point cloud and polygon processing. This class is referenced in the workshop_main.cpp to handle tasks such as:

    - Projecting 3D points onto a 2D plane (projToXYPlane()).
    - Line arrangement (line_arrange()).
    - Polygon clustering (poly_cluster()).
    - Circle arrangement (circle_arrange()).
    - Window and door detection (findwindows()).

These functions are heavily utilized throughout workshop_main.cpp to manipulate point clouds, fit geometric shapes, and generate polygons.

3. **CMakeLists.txt (build configuration)**: This is the CMake configuration file, which defines how the software is built. It includes configuration for:

   - Setting the project name and required CMake version.
   - Finding and linking necessary libraries: **PCL**, **CGAL**, **Boost**, and **Qt5**.
   - Handling dependencies and linking the PolygonHandel executable with required libraries.
   - Adding necessary definitions, like CGAL_USE_BASIC_VIEWER, for visualization components.

   The CMake configuration ensures the project is properly built with all dependencies, compiling the main source file workshop_main.cpp and linking it with PCL and CGAL libraries.

4. **seedsGenerating.cpp (implementation of seedsGenerating Class)**: This file contains the implementations of the functions declared in the seedsGenerating.h header file. This file is critical for providing the actual functionality for methods such as projToXYPlane(), line_arrange(), and poly_cluster(). It defines how the program processes point clouds, fits lines and polygons, and detects window/door features. Though this specific file is not provided in the current context, it is linked through the CMake file, indicating its importance.

Image_based opening detection: Utilizes an image-based opening detection method leveraging the YOLOv8 model to detect windows and doors from a dataset of building structural elements (Figure 45). The YOLOv8 model is tested to be applied to both videos and images captured by drones, enabling the precise identification of openings in building facades.

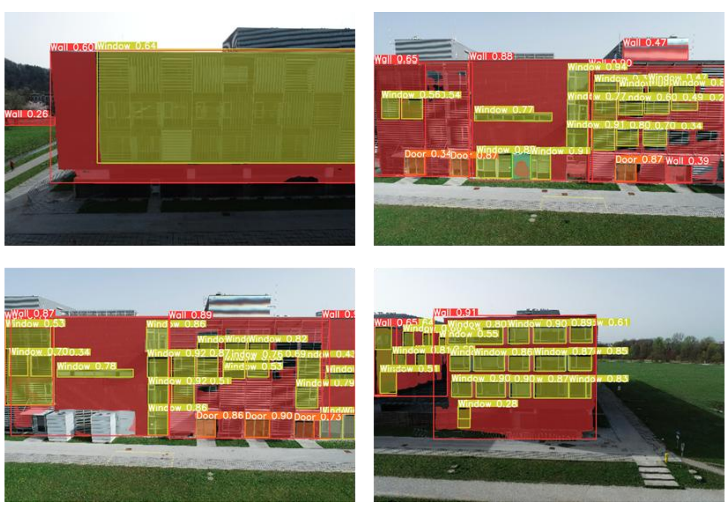


Figure 45. Results of opening detection – Ljubljana pilot

1. **Model loading and prediction:** The pre-trained YOLOv8 model is loaded using the `ultralytics` YOLO package, which simplifies the prediction process. In the case of video input, each frame is passed through the model to identify and detect instances such as windows and doors.
2. **Dataset processing and annotation:** The model predicts bounding boxes for windows and doors on each input frame or image. These predictions are annotated onto the frames/images using the `results.plot()` function, creating a visual output that highlights detected elements.
3. **Image segmentation from detections:** After predicting the building elements, the boundary coordinates of detected windows and doors are used to map them back to the original drone images. This mapping facilitates the segmentation of these openings on the building facade. This segmentation step isolates the detected windows and doors for further processing, such as measurement or analysis.
4. **Processing multiple images:** The method processes entire directories of images by iterating over each image file, applying the YOLO model, and saving the prediction results to the specified output directory.
5. **Drone image mapping:** The detected instances from the images or video frames are used to map the exact boundaries of windows and doors onto the drone-captured images. This allows for precise segmentation of the facade, enabling detailed analysis of the building's structural openings. The mapping process leverages the bounding boxes from the YOLO model to localize the elements on the facade.

GDT GENERATION

Obj2ifc: The **obj2ifc** method focuses on generating an IFC file from a 3D OBJ mesh. This process allows converting geometrical data from an OBJ file, which typically represents a part of a building into the IFC format:

1. **Loading and Parsing OBJ file**: The OBJ file is loaded using the `pywavefront` library, which reads the vertices and faces of the mesh. These vertices define the 3D coordinates of points, and the faces define how those points form the triangles or polygons of the 3D object.
2. **Setting up the IFC file**: A new blank IFC file is created based on a blueprint IFC template. This template includes necessary metadata like project information, geometric representation context, and building storey. This function sets up the essential IFC structure, such as the owner history, project, geometric context, and floor information, which are carried over to the new IFC file.
3. **Mesh creation and mapping**: Using the vertices (`v`) from the OBJ file, an `IfcCartesianPointList3D` is created, representing the 3D points of the mesh. Then, the faces of the OBJ are converted into `IfcIndexedPolygonalFace`, and combined into an `IfcPolygonalFaceSet`:

```
point_list = new_ifc.createIfcCartesianPointList3D()
point_list.CoordList = v
```

```
for face in fx:
    new_face = new_ifc.createIfcIndexedPolygonalFace(face)
    faces.append(new_face)

faceset = new_ifc.createIfcPolygonalFaceSet()
faceset.Faces = faces
faceset.Closed = False
faceset.Coordinates = point_list
```

4. **Placement and orientation**: The mesh is placed in the IFC structure using an `IfcLocalPlacement`, which sets the position and orientation of the roof in the building model. The placement relies on creating an axis and directional vectors, ensuring the correct orientation of the mesh within the building's coordinate system.
5. **Assigning representation**: The mesh is represented in the IFC file using a `IfcShapeRepresentation` with a "Tessellation" type. This representation indicates that the geometry is defined by triangular faces (or polygons).
6. **Attaching representation to the building element**: the created shape representation is assigned to the building object. This defines the actual geometry of the roof within the IFC model.
7. **Spatial structure assignment**: To integrate the roof into the building's spatial structure (such as floors, buildings, or sites), the roof is added to the `IfcBuildingStorey` container, allowing it to be part of the overall building model.

Txt2ifc: the creation of an IFC model from .txt file is based on the `ifcopenshell`, focusing on constructing a building hierarchy and adding geometry for walls, openings, and windows (Figure 46). The code is structured to handle both reading geometry data from external files and generating the appropriate IFC entities for a building's walls and openings.

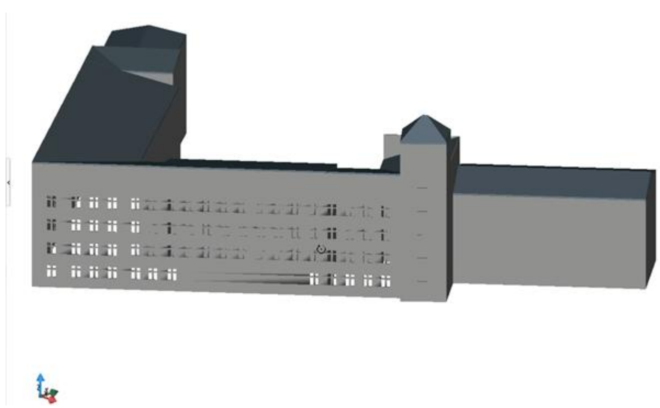


Figure 46. Generated gDT model – Riga pilot

1. **Reading façade points**: The code reads in a series of facade points from a .txt file, which are used to define the profile of the wall. These points represent the bottom profile of the wall geometry that will be extruded to form the full 3D wall.

2. **Wall creation**: The `create_ifclocalplacement()` function is used to position the wall in the IFC structure. The wall is defined using an extruded profile based on the points read from the facade file, creating an `IfcWallStandardCase`.
3. **Opening and window creation**: Openings for windows are created using `create_opening_and_window()`, which processes the files containing the points that define the boundary of the openings. For each set of points, an `IfcOpeningElement` and corresponding `IfcWindow` are generated. The opening geometry is subtracted from the wall using `IfcRelVoidsElement`, and the window is related to the opening using `IfcRelFillsElement`.

DT UPDATES

The workflow of the DT updates (Figure 47) represents a process for tracking construction progress using an as-designed IFC model with scheduled construction and multiple PCDs that are captured during the construction progress.

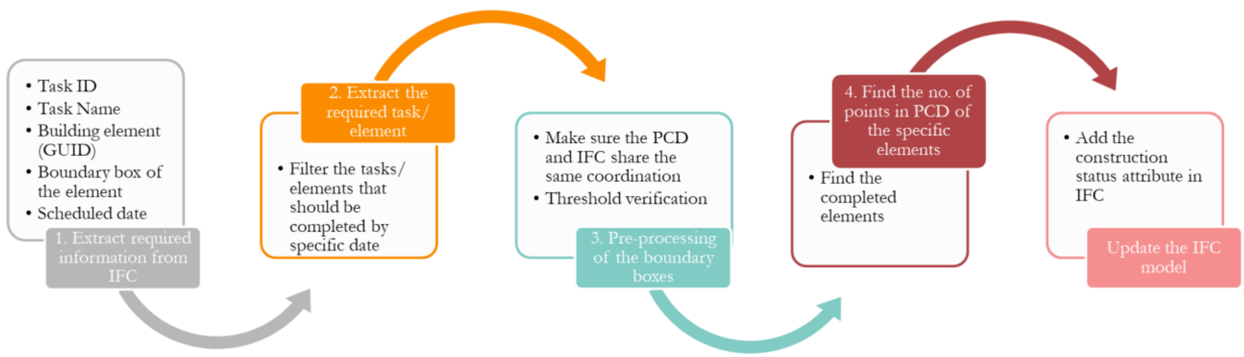


Figure 47. Workflow of updating the gDT

The first step in the process involves extracting the necessary information from the IFC model, which is a central data model used for managing building information. Key details that are extracted include the task ID, task name, the unique building element identifier (GUID), the boundary box that defines the spatial limits of the building elements, and the scheduled completion date for each task. This information is essential to define the scope of what needs to be analysed in terms of construction progress, providing a structured data set for further analysis.

Once the relevant information is extracted, the next step is to filter the tasks and elements to identify which ones should have been completed by a specific date. This filtering ensures that only the tasks that are relevant to the current construction milestone are included in the analysis. By focusing on scheduled tasks, the system can streamline the assessment process and prioritize the elements that should be examined for completion.

In the third step, pre-processing is performed on the boundary boxes of the building elements to ensure that the PCD and the IFC model share the same coordinate system (Figure 48). Additionally, a threshold verification is applied to account for tolerances, ensuring that small deviations in the data do not lead to incorrect results. This pre-processing step guarantees the integrity and accuracy of the data before progressing to further analysis. The below picture shows the mapping between boundary boxes extracted from IFC elements with the point cloud model captured during construction timeline.

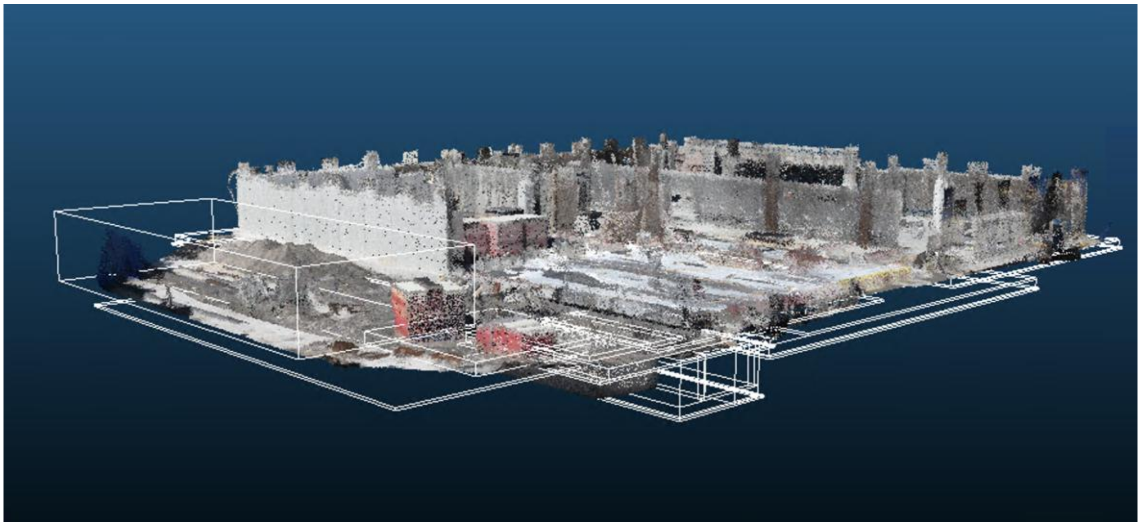


Figure 48. mapping between the IFC elements and construction point cloud data – Polish pilot

After the pre-processing, the system proceeds to count the number of points in the PCD that correspond to the specific elements extracted from the IFC model. The presence of sufficient points in the PCD within the boundary box of a building element indicates that the element has been completed. This step is vital for identifying completed elements by analysing the actual construction progress on-site, as represented by the point cloud data.

Finally, the IFC model is updated with the construction status of each element. For those elements identified as completed, the system adds the relevant status attribute to the IFC model. This step keeps the model synchronized with real-time construction data, ensuring that project managers and stakeholders have an accurate and up-to-date representation of the building's progress. By updating the model, the system provides a clear and dynamic picture of which tasks have been completed and which are still in progress, enabling better project tracking and decision-making (Figure 49).

```
Element with GUID 0SOqSLgbL02vPmfn23gVOG updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 2a_JwKAhX2weU_5bcIMExQ updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 1KVzLToTr72QLldg3nbiUE updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 3qc2tbh2P1ORSe6o5E_8MS updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 1rO_LfDWz3mQvxfPXc_EmX updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 0imi_PC7j4MAuEJxHzoRDP updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 2gccaj68X8ghjd1tUCg5xw updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 1ThBBWTibD8hDn4WJ4LVqw updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 3oIQSKeTf6j8y19dgu$AWL updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 2DtfbH0nH0uBhyLYArKv2Q updated: Status -> Undetected, UpdatedDate -> 27 May 2024
Element with GUID 10s2_cjjn2SuASzUxQpf5I updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 2a3XZXNjL2vQ$fkqNZNwLW updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 02hFqCyH1F4uh9MO3D6_Ap updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 3Ml4MMwzbBIv7USqZQCD7k updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 3PDB$tHG999Ba54vUISfna updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 0dO19sk6X7Th6UTdpS_8E4 updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 0rmMuMizb2LQJ2SrEE5BRn updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 1qIgV740PB_B$I3wCwMJt0 updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 1nwjuIFnX8FeGJwzlygR34 updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 04br$ZCoD3hRzK1n9UPqds updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 2H6FAN42XBrPGoTeqYCBbA updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 1PxBGBOEr00hcoi9CZKkbA updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 3G4Ku1rLv6q8K$NcuD27yu updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 2Btd9QWcr7Wf04$WofF4BA updated: Status -> Completed, UpdatedDate -> 27 May 2024
Element with GUID 173s7Fh5rBVQIV_f3tSeU3 already completed. Skipping.
Element with GUID 3aTwLCwBD1GvRXCoI4k_fP already completed. Skipping.
Element with GUID 3EPLue1jj5txsl1P3pjvN5 already completed. Skipping.
```

Figure 49. Logs of updating the construction status

3.4.2. SE2. Digital Twin Enrichment

SE2 has established the core framework for all the functionalities developed so far (Figure 50). While most processes are still in progress and not yet finalized, the key elements have been successfully implemented. This provides a solid basis to continue working on improving, and refining these functionalities to reach their full potential.

	% Completed			Comments
	Previous development	Pilot 1 (Warsaw, Poland)	Pilot 3 (Piraeus, Greece)	
Data collection (RGB)	100%	100%	100%	Completed
Data collection (Thermal)	100%	20%	100%	Pilot 1 - Thermal drone flight in nov/dec
SLAM	100%	20%	-	SLAM data collected but not processed
RGB Mesh	100%	100%	100%	Completed
RGB point cloud	100%	50%	100%	Pilot 1 - Lack of SLAM processing and integration with external cloud
Image Calibration (thermal)	100%	100%	100%	Completed
Image matching (thermal)	75%	0%	50%	Improve the matching process to be applied in pilots Pilot 1 - Lack of thermal images
Thermal mesh	75%	0%	50%	
Thermal point cloud	75%	0%	50%	
Crack detection	80%	0%	50%	Refine crack detection
Thermal Bridges detection	30%	0%	10%	Work on thermal bridges detection
Dampness detection	30%	0%	10%	Work on dampness detection
Solar panels detection	80%	0%	0%	Refine solar planels detection Lack of solar panels dataset in pilots
Reports	10%	0%	0%	Automatize reports generation

Figure 50. SE2 progress of processes for the two pilots at current status

RGB MESH AND POINT CLOUD GENERATION

Through photogrammetry, meshes have been developed for each pilot project, with the corresponding RGB texture accurately projected onto them. From these meshes, point clouds have been generated, achieving a precision of 5 mm. To enhance accuracy, the point clouds have been georeferenced using control points provided by the pilots, which improve the RTK (real-time kinematic) positioning data from the drone cameras. This high level of detail and precise georeferencing allow for accurate modelling of surfaces, enabling thorough analysis and further processing, such as the detection of anomalies or integration with other datasets. The use of photogrammetry ensures that the geometric and visual information is well-aligned, providing a reliable basis for subsequent stages of analysis and visualization.

In both pilot projects, the development of the meshes and point clouds has been successfully completed, finalizing the process for the RGB components of the meshes and point clouds. This completes an important step, ensuring that the visual and geometric data are accurately represented and ready for further analysis and integration.

THERMAL MESH AND POINT CLOUD GENERATION

For the development of the thermal components within the models, a method of projecting thermal images onto the RGB-generated mesh was chosen. This approach allows for the integration of thermal data directly onto the detailed, high-resolution RGB models, providing a comprehensive view of both visual and thermal characteristics.

To achieve this, various scripts were developed for calibrating the thermal images, converting formats, and adjusting colour treatments. Additionally, several matching algorithms were applied to ensure precise alignment of the thermal images with the RGB meshes. The projection technique enables thermal imagery to be accurately overlaid onto a model created using drone-captured RGB images with a 50% overlap, significantly reducing both the processing time and the duration of the drone flights. This method not only enhances the efficiency of data acquisition but also ensures that the thermal data is seamlessly integrated, allowing for a more detailed and accurate analysis.

CRACKS DETECTION

The process of detecting cracks in buildings using the YOLO (You Only Look Once) model involves several key steps, beginning with data pre-processing, followed by training the model to identify cracks, and ultimately deploying it for image detection.

During the data collection and pre-processing phase, high-resolution building images that align with the expected input from pilots were meticulously selected and labelled. These images were divided into smaller sections to fit YOLO’s input requirements and underwent data augmentation to enhance the model’s robustness and diversity. The crack detection system is currently in an iterative phase, continuously refining its outputs through ongoing training. This fine-tuning process, supported by the Magerit supercomputer, aims to improve the model’s precision and reliability. The continuous cycle of monitoring and adjustments ensures that the YOLO model remains effective in detecting cracks in building structures.

Once the model is fully trained, the workflow will be applied to new images, detecting cracks by generating bounding boxes around them and providing accurate labels. Post-processing scripts will filter out low-confidence predictions, ensuring that only the most reliable detections are retained, thus making the crack detection process both more accurate and efficient. Additionally, to enhance the filtering of areas of interest, automatic image masks have been generated to distinguish the context of the images, as well as various constructive elements, including roofs, doors, and windows.

Finally, the detected images will be projected onto the model, resulting in a three-dimensional representation that facilitates spatial localization and quantification.

SOLAR PANELS DETECTON

Similar to the process used for cracks detection in buildings, the YOLO (You Only Look Once) model is also applied to detect defects in solar panels, following a similar approach in several key stages, from data pre-processing to model training and deployment for image detection.

During the data collection and pre-processing phase, images of solar panels resembling the expected input from the user were selected and labelled. These images were resized to a suitable size for YOLO and underwent data augmentation techniques to improve the model’s diversity and robustness. Currently, the detection of anomalies in solar panels is in an iterative phase of training and refining the model's outputs. This fine-tuning process is being conducted using the Magerit supercomputer to enhance the model’s accuracy and reliability. The iterative cycle of monitoring and refinement ensures that the YOLO model remains effective in identifying defects in solar panels.

The trained YOLO model will be used to detect anomalies in new images. Its predictions will generate bounding boxes around detected anomalies, each labelled accordingly. After detection, post-processing filters will be applied to remove low-confidence predictions, ensuring that only the most accurate detections are considered, thereby making the overall detection process more reliable and efficient.

THERMAL ANOMALIES DETECTION

Thermal anomalies are detected by analysing the temperature distribution within the 3D point cloud. Specifically, anomalies are identified as points where temperatures deviate significantly from the expected range, based on statistical analysis of the data. To determine what constitutes an anomaly, the system uses statistical methods to establish a normal distribution of temperatures for the surface. Any points with temperatures falling outside this range are flagged as potential anomalies.

Once anomalies are detected, they are further classified into two categories: linear or superficial. This classification is based on the geometric features of the anomaly, which are determined by analysing the spatial structure of each point and its neighbouring points. Principal Component Analysis (PCA) is applied to extract these features, allowing the system to distinguish between anomalies that appear as linear features, such as elongated thermal bridges, and those that are more spread out or superficial, like areas of dampness or surface heat variations. This approach ensures accurate and efficient identification of different types of thermal anomalies, enabling a more detailed assessment of potential issues.

REPORTS

The SE2 service will generate detailed damage reports to provide insights into detected anomalies, covering various types such as thermal anomalies, solar panel malfunctions, and cracks. These reports are structured to include essential data regarding the location, type, and severity of each anomaly, as well as recommendations for addressing identified issues. Currently, reports are generated manually, but efforts are underway to automate data processing to optimize workflow and efficiency.

<u>Thermal Anomaly Report</u>

The Thermal Anomaly Report identifies malfunctioning cells within solar panel installations, detailing the location by row and column and noting temperature differences from the panel's normal range. As these anomalies often appear only in thermal images, the report specifies thermal visibility to support prompt attention to energy output and efficiency.

<u>Solar Panel Anomaly Report</u>

The Solar Panel Anomaly Report identifies malfunctional cells within solar panel installations. Each report details the location of affected cells by row and column within the panel, as well as the temperature difference between the malfunctioning cells and the panel's normal range. Since these anomalies are often only visible in thermal images, the report specifies thermal visibility, ensuring prompt attention to energy output and efficiency.

<u>Crack Report</u>

The Crack Report details cracks in building façades or structural elements, including their location, orientation (vertical or horizontal), and size. Temperature data assess thermal impacts, and visibility in both RGB and thermal imaging is noted to support proactive maintenance planning. Each report ends with remediation recommendations based on detected anomalies and may related images or data files for further analysis by maintenance teams.

3.5. Next steps

3.5.1. SE1. Digital Twin Generation

Consolidate the Digital Twin Generation solutions:

- **Integrate obj2ifc and txt2ifc workflows**: Merge both workflows into a unified pipeline for handling OBJ and TXT files.
- **Optimize efficiency**: Implement multi-threaded processing for faster data handling and geometry creation.

Consolidate the Digital Twin update solution for construction scenarios:

- **Continuous implementation:** Continuously implement the following scans data (drone flights to collect the point cloud data for the cases in during construction, such as the Polish Pilot) to update the construction status information in the digital twin model.

Visualization development solution:

- **VR/AR visualization module**:
  - Integrate with VR/AR engines (e.g., Unreal Engine, Unity) for immersive experiences.
  - Add the digital twin and thermal related information into the VR/AR environment
  - Add interactive features for model navigation and task-related views (e.g., building elements' attribute checking or various formats of model selection).

- **Screen-mode visualization module**:
  - Use open-source tools to create a web or desktop-based viewer.
  - Develop 3D visualization capabilities for interacting with digital twin models.

3.5.2. SE2. Digital Twin Enrichment

The next steps for SE2 involve further advancing and refining current developments. Since anomaly detection results are still in the testing phase, processes and methodologies will need adjustments to enhance outcomes. The main next steps are as follows:

Model development

Pilot 1 (Poland)

- Final result of the RGB point cloud:
  - Integration of interior scanning with the exterior cloud
  - Clean the point cloud
- Final result of the thermal point cloud
  - Support thermal flights for the pilot
  - Thermal image processing
  - Calibration of thermal images
  - Projection of thermal images onto the RGB model to generate the thermal point cloud

Pilot 3 (Greece)

- Final result of the thermal point cloud
  - Improve thermal projection for better projection results

Anomaly detection (cracks)

- Enhance detection accuracy using Artificial Intelligence
- Improve the filtering of valid cracks (false positives)
- Train the Artificial Intelligence for better results
- Improve the representation of anomalies on the model

- Apply detection in Pilot 1 (Poland) and Pilot 3 (Greece)

Thermal anomaly detection (thermal bridges and dampness)

- Enhance detection accuracy using algorithms based on statistical methods
- Improve anomaly filtering
- Improve the clustering classification of anomalies
- Enhance representation
- Apply detection in Pilot 1 (Poland) and Pilot 3 (Greece)

Detection of damage in solar panels

- Enhance detection accuracy using AI
- Improve the filtering of false positives
- Train the AI-model for better results
- Improve the representation of anomalies on the model
- Apply detection in Pilot 1 (Poland)

Reports

- Improve report format
- Test generating reports automatically

4. BUILDSPACE services at city scale: Built Environment Climate Scenarios

The Built Environment Climate Scenarios (SE3) aims to estimate the **current energy demand** (heating, cooling and Domestic Hot Water (DHW)) of **residential building stocks** based on the generation of simplified models. Additionally, it will calculate how this energy demand evolves under various **climate change scenarios**, according to the standard accepted CMIP6 scenarios (SSPs-RCPs). This analysis involves downscaling climate data and applying bias-correction with historical data from weather stations. By examining the impact of different climate scenarios on energy performance, the stakeholders will gain valuable insights into how future energy demand will be affected by climate change, enabling informed decision-making.

After the demand evaluation, this service includes the calculation of relevant KPIs to evaluate energy efficiency gains through the definition of different **retrofitting strategies** (e.g. changes in building envelope, energy system, change in energy use profiles). These strategies may be chosen by the user (and try different combinations) to evaluate the reduction in both energy demand and consumption of a building, and thus, better analyse the benefits or worthwhile of the interventions, while considering the effects of climate change in the upcoming years.

In addition, the **solar PV potential** on suitable rooftops of the building stock is calculate, supporting the decision-making processes for PV deployment as well as encouraging building owners to take action. This PV potential will be used as available electricity to reduce the consumption of the heating or cooling system being integrated as part of the proposed retrofitting strategies.

The service operates through a user-friendly web tool with a coloured map as basis for the delivery of the information in a very visual manner.

4.1. Input and output

The **inputs** used by the service are the following:

- **Buildings' information** needed:
    - Buildings' geometry (boundary and area, including façade and party walls area)
    - Year of construction of buildings
    - Buildings' height
    - Buildings' use and/or typology
    - Building characteristics (whether available): thermal characteristics for the envelope, window-to-wall ratio, energy systems (including district heating data), others (e.g. glass reflectivity).
- **Data sources** for buildings information: **cadastral** data (provided by the pilot) and **OpenStreetMap** (https://www.openstreetmap.org/). Both are usually needed because cadastres often have poorly constructed geometries, e.g. in order to detect party walls correctly, while OSM

does not contain other key information such as the year of construction of the buildings or the building height.

- Digital Surface Model (**DSM**) and Digital Terrain Model (**DTM**), or LiDAR data instead.
- High resolution raster images of the pilot area.
- Historical **data from weather stations** (at least from 30 years) or historical data in grid format for 30 years.
- Data from **PVGIS**: solar radiation and PV production potential according to the PV technology, location, azimuth and slope (https://re.jrc.ec.europa.eu/pvg_tools/en/).
- Buildings' **retrofitting** measures information (as well as national prices).
- Solar data from **Global Solar Atlas** (https://globalsolaratlas.info/).
- Future climate data: three models (SSP245, SSP370 and SSP585) with data on a daily basis from 2024 to 2100 aggregated at three reference periods (up to 2030, 2040 and 2050). Five different climate models from **Copernicus C3S** will be used in order to reduce bias between model results.

The **outputs** of the service are the estimation and visualisation of the energy demand of the residential building stock, both at building, district and city level. Additional information of each building is also provided, including the average geometry characteristics and the energy performance values, for heating, cooling and DHW energy demand, and the Solar PV potential of the building rooftop. Future projections at three climate scenarios and at three different time frames will be also available under user selection. Additionally, the tool allows the comparison of the energy demand at the different scenarios (including the baseline scenario).

An additional service output is related to the KPIs on retrofitting strategy gains, applied to a selected building or set of buildings to evaluate how the energy demand and consumption can be reduced through the application of different measures, allowing also for comparison between them in terms of energy and investment required.

4.2. User experience

The **urban stakeholders** from municipal departments can use the service to make informed decisions, identifying priority areas of the city for energy renovation and promoting funding or incentives for building owners. Solar PV data can also help municipalities to promote high-potential public rooftops for the creation of energy communities, encouraging citizen investment and participation in the energy transition. Other stakeholders, like construction and PV installation companies, can use the information to target building needing energy upgrades or high solar potential, gaining a competitive edge.

Citizens, such as homeowners or residents, can benefit from the service by being informed of the energy demand of their building and compare it with that of their neighbours (stimulating the will to take action and improve the own dwelling). They can simulate different energy retrofitting scenarios in their building to evaluate the effectiveness for energy and economic savings, encouraging them to make a safe investment in their own building. With the information of the suitability and potential PV production of their roof, they could also be encouraged to make an investment considering the PV installation cost and payback period of the initial investment.

The complete **user experience** (or **service workflow from user perspective**) is included in Figure 51 below.

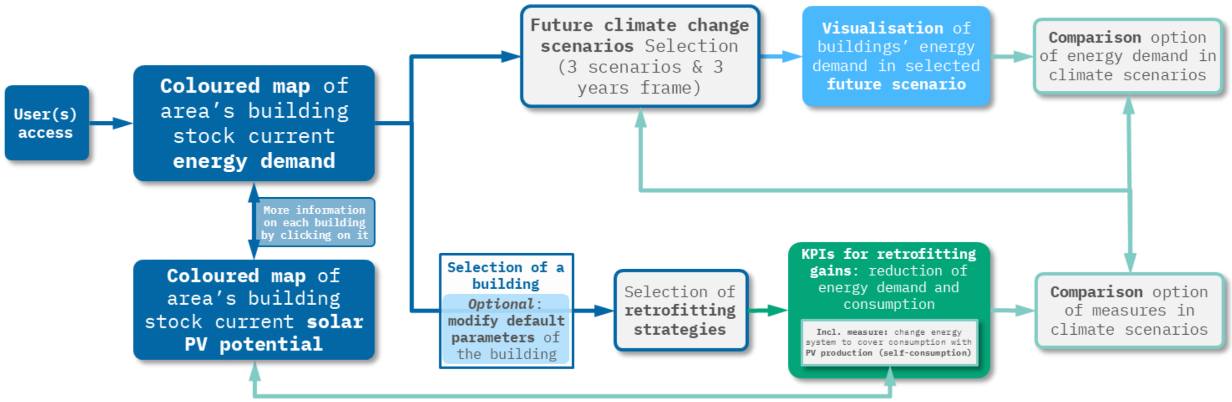


Figure 51. SE3 Built Environment Climate Scenarios user experience (service workflow from user perspective)

The service will be accessible through the BUILDSPACE Core Platform, and user log in is needed (Figure 52).

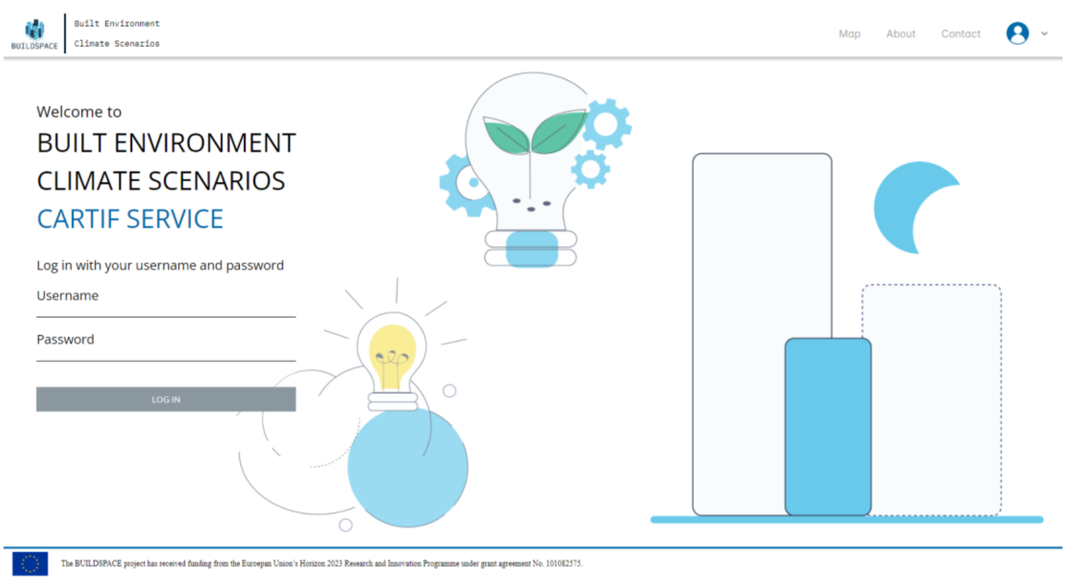


Figure 52. SE3 user log in

When entering the service, a map of the building stock is shown (Figure 53), coloured according to the heating demand of the residential buildings. The colour scale, which can be seen below on the right, is hardcoded according to the Energy Performance Certificate (EPC) labels of the country (in this case Latvia). This can be also visualised at other scales, providing aggregated information on district and city level (Figure 54). On both maps, a pop-up is displayed when the mouse is hovered over a building or district. For the case of the building, the pop-up shows the energy demand value, while for the districts, it shows the name of the neighbourhood and the average value of the energy demand.

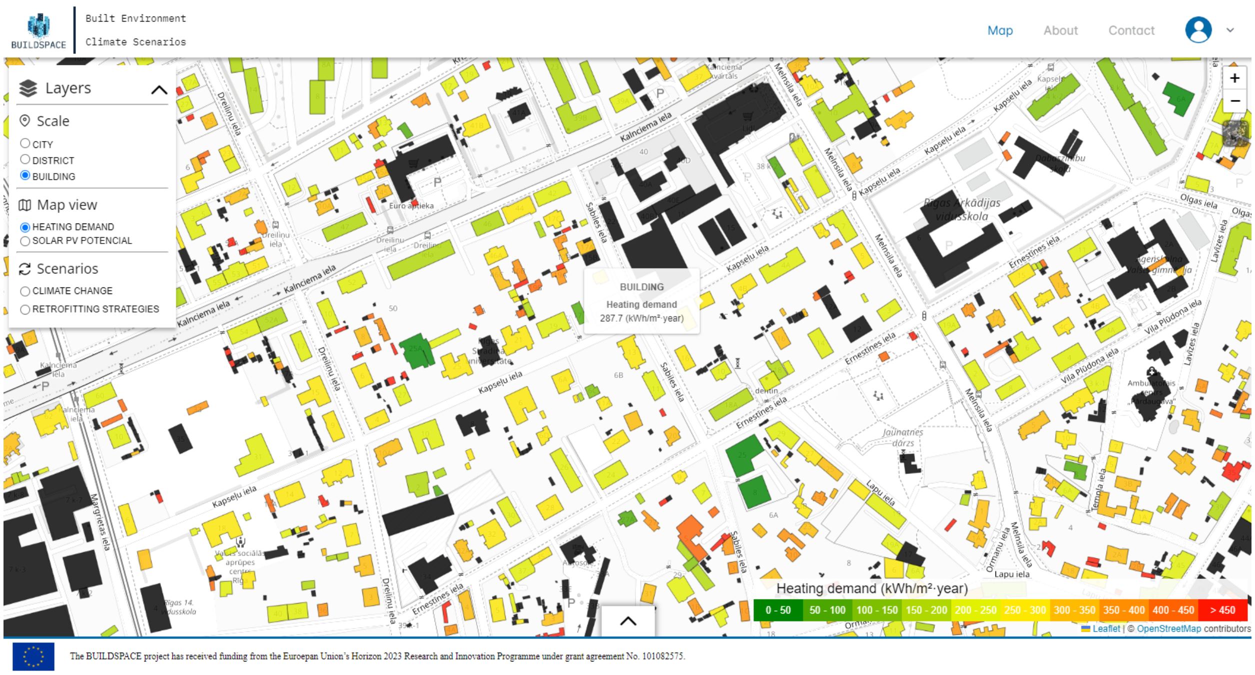


Figure 53. SE3 map with heating demand of the residential building stock (non-residential buildings are shaded in black)

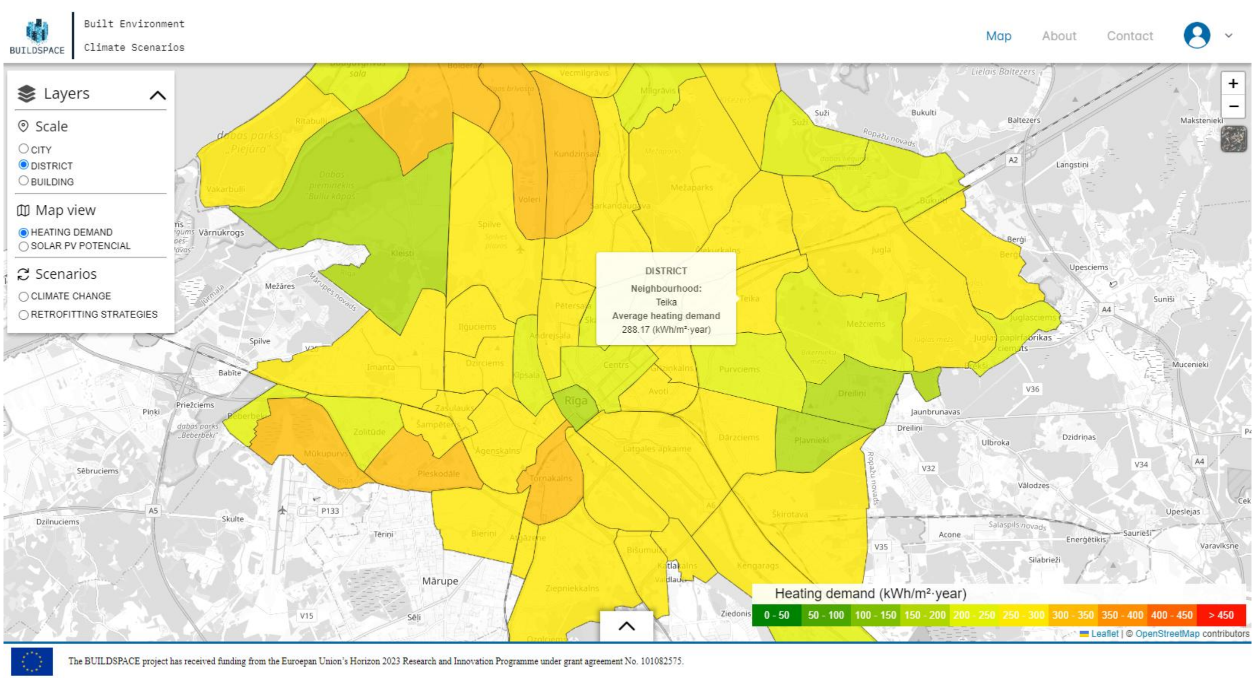


Figure 54. SE3 map with heating demand aggregated at district level

Further information on what it is being displayed in the map (on the screen) is provided through the bottom data panel, that appears when clicking on the arrow below (Figure 55). The data panel calculates several relevant metrics based on the buildings that are located in the map on the screen, such as number of buildings and their average heating demand. It also contains a representation of the number of heating demand classes (labels) and the year of construction. This panel is interactive and user can filter either by heating demand class or by construction year (see examples in Figure 56 and Figure 57).

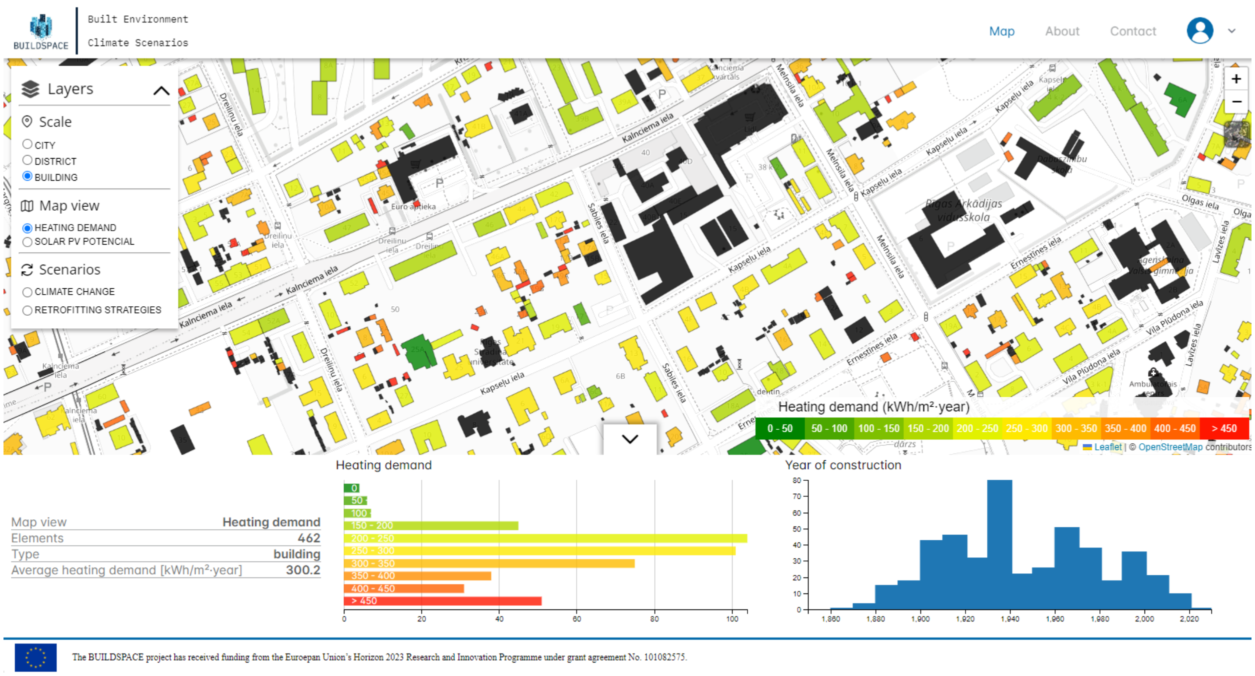


Figure 55. SE3 map with heating demand with the bottom data panel displayed

Figure 56. SE3 map with heating demand with the bottom data panel displayed, filtering in yellow label (250-300 kWh/m² year) for heating demand

Figure 57. SE3 map with heating demand with the bottom data panel displayed, filtering by year of construction (years from 1840 to 1940)

Furthermore, a left side panel is displayed when clicking on a building (Figure 58). It contains general information of the building: year of construction, typology, current use, total surface and number of floors, as well as average geometry characteristics (with final figures on façades surfaces, windows, party walls, roof, floor, volume above ground and compactness ration). Finally, it includes the energy performance values estimated for the building, including heating demand, cooling demand and domestic hot water (DHW) energy demand.

Figure 58. SE3 general map with further information of a selected building at the left side

The climate change scenarios function is also available at this stage, though data will be refined by the next technical release. It is accessible through the scenarios' subsection in the *Layers* selector. It allows to select between the three available climate change scenarios (including an explanation of what each of them implies), as shown in Figure 59; and then between the three future time frames (2030, 2040 and 2050), for which the energy demand will be visualised (Figure 60).

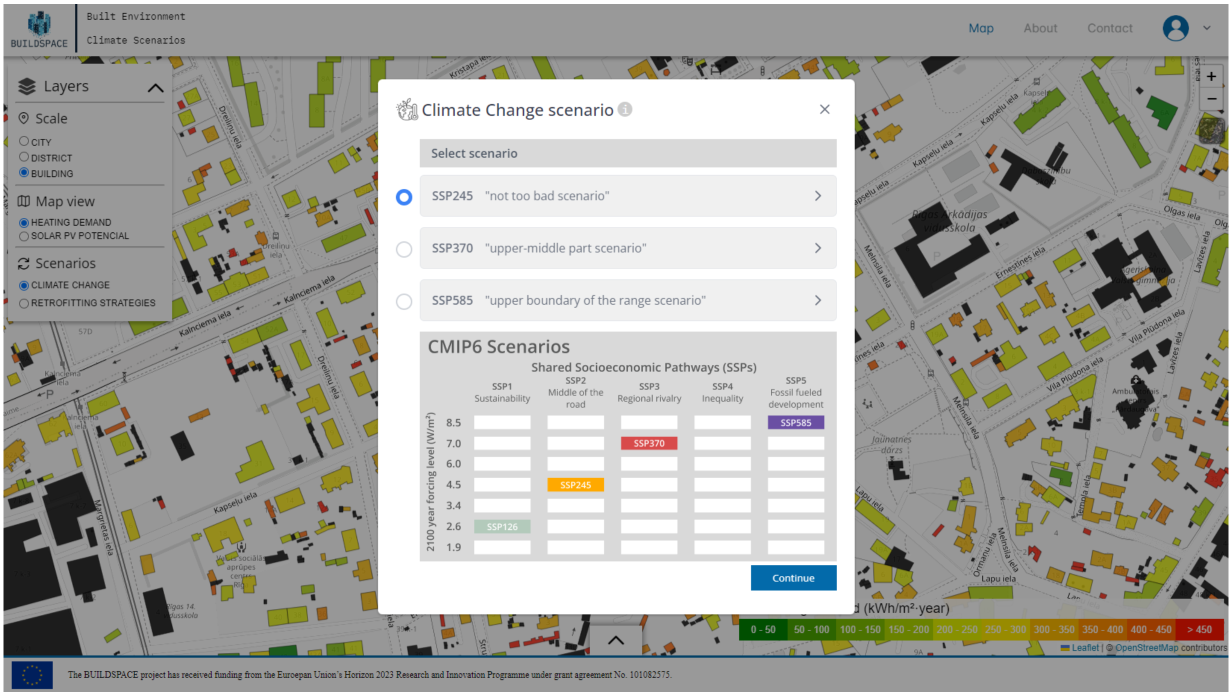


Figure 59. SE3 dialogue box for the climate change scenarios selection (first step: selecting scenario)

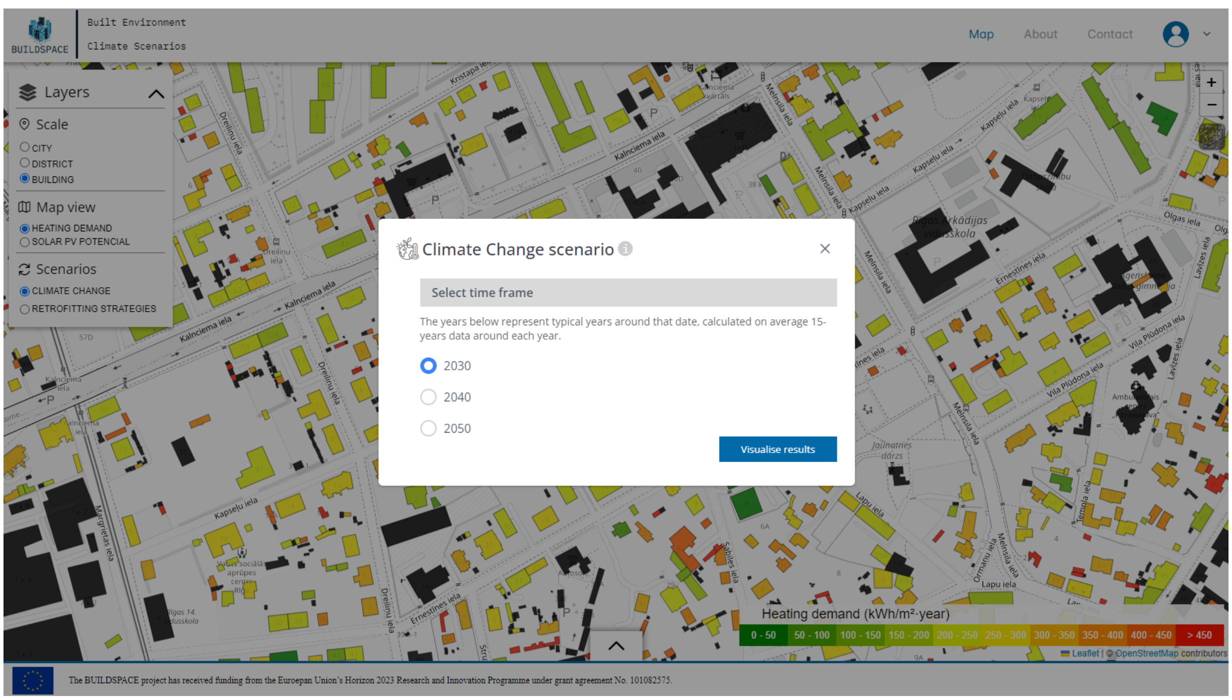


Figure 60. SE3 dialogue box for the climate change scenarios selection (second step: selecting time frame)

Then, the selected climate change scenario is shown in the map (with a blue warning on what is being viewed in the *Layers* box), as shown in Figure 61. The function for comparing this selected climate change scenario with the baseline one (the general one, with the present or current energy demand) is activated with a blue button.

Figure 61. SE3 map with a selected climate change scenario visualisation

The final feature of the service, which will be available in the last technology release, is the *Retrofitting strategies* scenarios within the *Layers* selector. A user needs to select a building on the map to apply various renovation strategies. They will then have the option to choose measures from four key renovation areas: envelope insulation, window replacement, change of energy systems and behavioural change (assessed through different savings profile). Each category offers additional details and options, which are displayed when selected, allowing users to explore the specific measures in more depth.

As can be seen in the *Layers* selector of all previous screenshots, the application will include also the solar PV potential map, although this is not yet integrated. For the moment, the PV potential map is available in a different format, as shown in Figure 62, where the buildings' rooftops are coloured based on their solar PV potential, according to the legend provided (in MWh/year). Also, as shown in Figure 63, additional information, like the rooftop area, the nominal solar radiation, the suitable rooftop area, the number of PV panels that can be installed, the kW peak, the PV potential and the investment cost is also provided when clicking on a building.

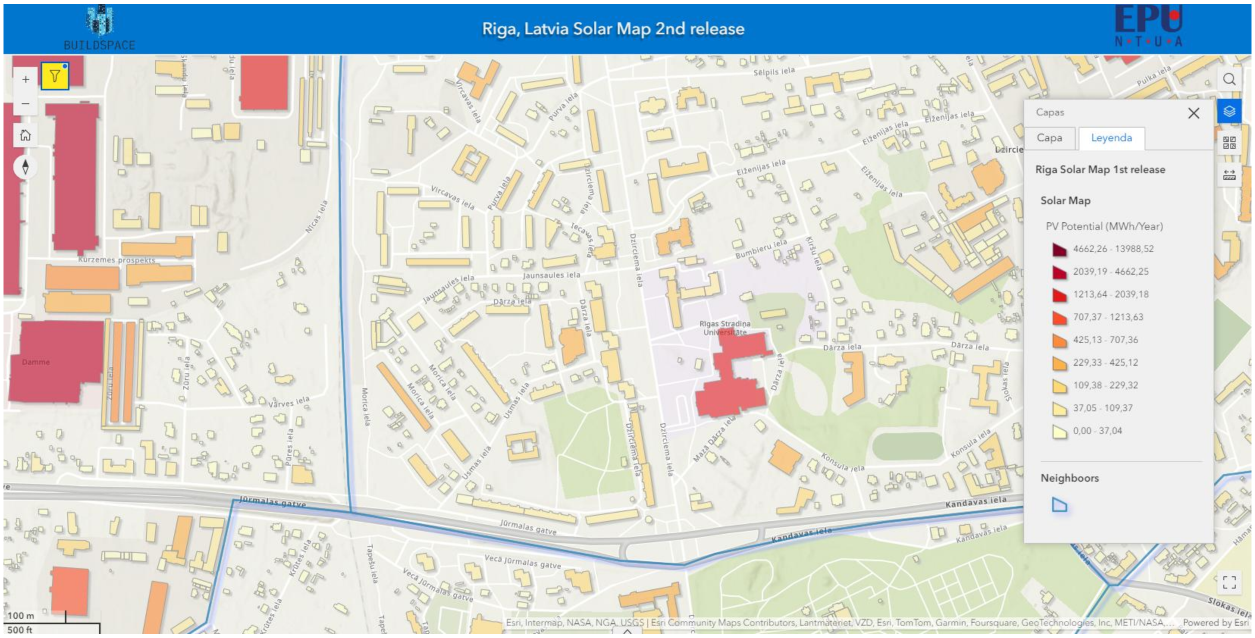


Figure 62. SE3 map (provisional interface) with solar PV potential colouring the building stock according to the legend shown

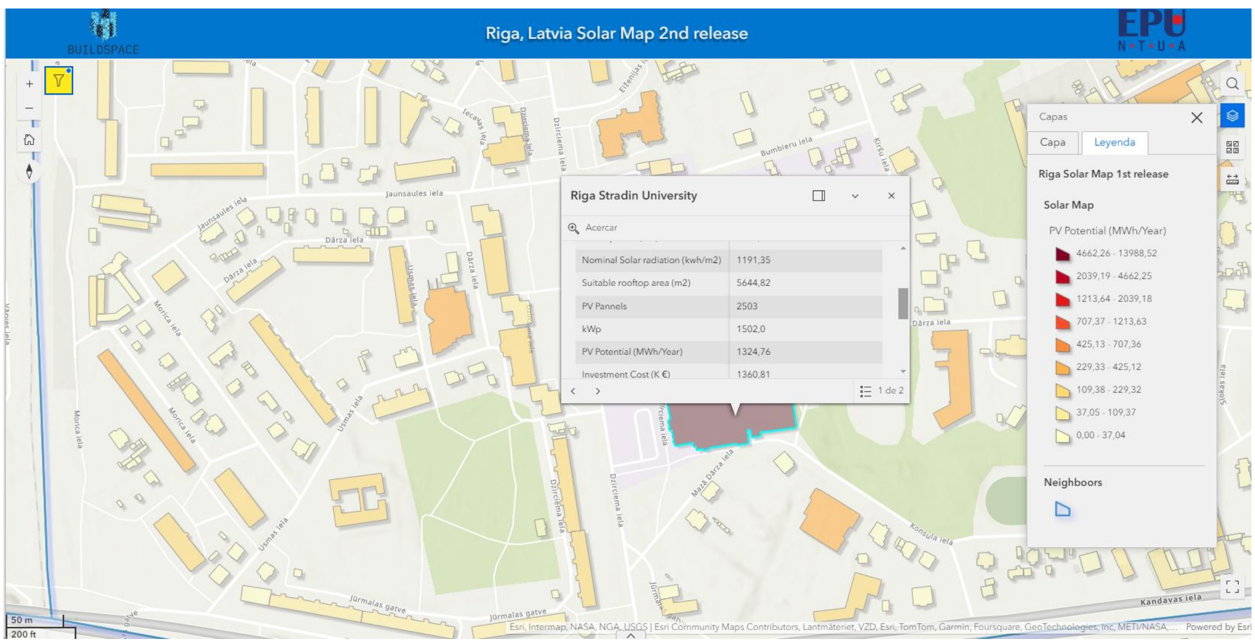


Figure 63. SE3 map (provisional interface) with the additional information provided when clicking on a building

4.3. Application to pilot and replication potential

The service is being fully developed for Riga, Latvia (Pilot 2 of BUILDSPACE), with tailored features based on specific needs identified through discussions with Riga's stakeholders. These insights have influenced the customisation and addition of functions, detailed in the following subsection 4.3.1.

4.3.1. Service personalisation according to pilot interest

Energy demand predictions: The service provides reliable energy demand estimates at both building and city levels, considering **climate change impact.** This helps in planning renovations by offering insights into the current building status. The service relies on reliable databases and sophisticated algorithms that have been already tested in other countries as part of other research projects (less advanced versions).

Focus on residential buildings: The service focuses on residential buildings, encouraging competition by allowing users to compare their building's energy efficiency with neighbours. A colour scale based on national EPC labels shows room for improvement and potential energy savings. Additional building information, such as age and surface area, ensures fair comparisons.

Multi-scale data visualisation: The service offers data visualisation at district scale and city scales. Districts are defined according to neighbourhoods in Riga (https://apkaimes.lv/). But users can also define custom districts to tailor energy planning (future functionality for the final technology release).

Map-based visualisation: The intuitive map interface visualises energy demand and solar PV potential, highlighting suitable rooftops. Coloured maps and clear legend provide a user-friendly entry point.

Retrofitting strategies scenarios: Professionals can model various retrofitting measures and evaluate their energy and economic impact through relevant KPIs (functionality that will be developed for the final technology release). The input from Riga helped build a reliable cost database and standard intervention catalogue.

Solar PV potential: The service provides data on rooftop solar potential, aiding social acceptance and encouraging energy community participation. Data is shown on the map, with figures for each building's solar output in MWh per year.

District heating consideration: Given the widespread use of the district heating (DH) in Latvia, retrofitting scenarios account for buildings connected to DH. Riga provided data on DH connections, and users can modify energy system settings for accurate simulations.

PV integration in retrofitting strategies: Solar PV installation will be included in the retrofitting strategies as part of the energy system upgrades. PV energy can be used to power heat pumps, improving energy efficiency for heating, cooling and DHW.

Heritage buildings consideration: PV installation suitability accounts for architectural heritage restrictions, important for Riga's many heritage buildings. Cultural heritage data from Riga ensures compliance with legislation.

Economic investment and savings: The service provides cost estimates for retrofitting and PV installation, along with potential savings, using agreed-upon pricing with Riga.

Climate change scenarios in retrofitting KPIs: Retrofitting KPIs consider future climate change impacts, helping users evaluate the long-term benefits of interventions. Scenarios are compared to historical data and future projections, creating awareness of climate change's effects.

Behavioural change measures: Energy savings from user behaviour changes are included in the retrofitting strategies. Different "savings profiles" will be provided, highlighting potential energy savings based on slight comfort temperature adjustments and occupancy patterns.

4.3.2. Service replication potential

The service functionalities and considerations from the pilots significantly enhance its value, making it highly attractive to municipalities across Europe and beyond. The service is both **replicable and scalable**, primarily due to the universal interest among urban stakeholders and citizens in European cities. These cities often have a substantial number of older buildings with low energy efficiency and are increasingly impacted by climate change, despite a lack of concrete data on changing energy demand patterns. Additionally, the service leverages a considerable amount of open data and other commonly available datasets in cities, facilitating its adaptation to other territories.

The core potential of this web tool lies in its ability to estimate energy-related indicators and parameters for a large number of buildings using public information sources. For building geometries and characteristics, the service utilises OpenStreetMap open data. While it provides valuable insights for building footprints and basic attributes, it lacks key information such as the year of construction of the buildings, and the heights, although the latter can be sourced from other public datasets (usually cadastre data). For detailed building typologies, the service employs TABULA/EPISCOPE data, which offers information on the walls, roofs, floors and windows characteristics categorised by construction year ranges for each country. However, this data varies by country and is not available for all European counties, needing assumptions and interpolations for those not covered.

The primary challenge in replicating this service is gathering sufficient data to develop robust and accurate prediction models for the estimation of the energy demand of a city's building stock. Additionally, the retrofitting strategies functionality requires detailed information on materials and costs at the country level. For the solar PV potential estimation functionality, comprehensive data on building rooftops and cultural heritage buildings is essential to assess their suitability for PV installation.

In conclusion, while there are challenges related to data availability and consistency, the service's reliance on open data and its adaptability to local datasets make it a promising tool for cities across Europe. By addressing these data constraints, the service can provide valuable insights into energy efficiency and support sustainable urban development.

As will be seen in SE4 section (subsection 5.3), part of the service is already being replicated for the Pilot 3, Piraeus (Greece).

4.4. Technical development update: second technology release

Taking advantage of the progress done for the first technology release for a district of the city, the development for the estimation of the energy demand has been extended to the whole city of Riga. As can be seen in the workflow in Figure 64, the map and XML data from the cadastre are merged to obtain the geometry of the building footprint and its metadata. In parallel, the OpenStreetMap data is processed. Both geometries are joint and processed to obtain the buildings and façades geometries. For the geometry of the buildings OpenStreetMap is preferred because its geometrical information is more accurate. Some adjustment processes have been applied to the dataset in order to validate the geometries. Then, with the geometries in it, the typology is generated (using TABULA/EPISCOPE data), together with the assignation of use, year of construction, characteristics and solar radiation. If the data is incomplete or not available, then information from the different sources will be used and different assumption are made. Heating and Cooling Degree Days (HDD and CDD) are calculated also to finally estimate the energy demand (heating, cooling and DHW demand) by running the algorithm with these data for the whole city of Riga.

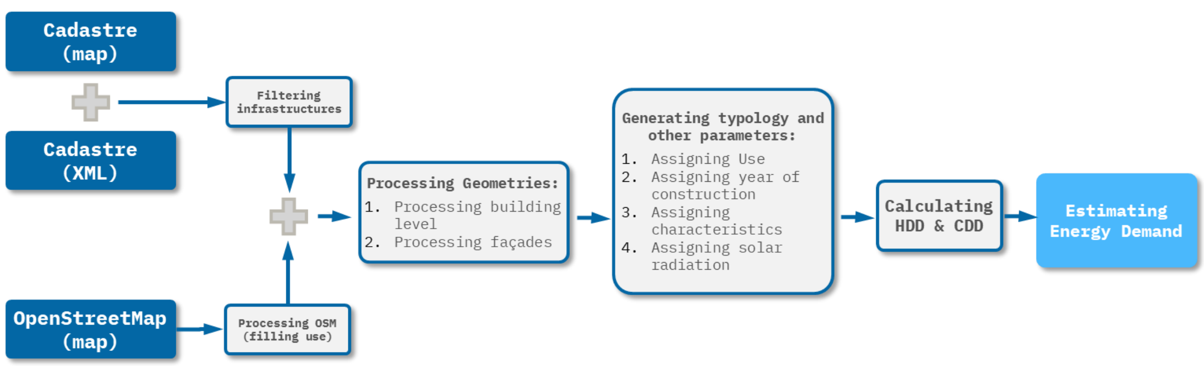


Figure 64. SE3 Energy demand estimation workflow

The calculated energy demand is then related with the Latvian EPC labels to be able to colour each building in the map according to their performance, while providing a simple understanding of the buildings' performance with the colour legend (Figure 65).

Figure 65. SE3 Heating demand colour scale according to Latvian EPCs

The CMIP6 (Coupled Model Intercomparison Project Phase 6) scenarios consist of a series of climate modelling experiments designed to understand future climate change under different conditions. These scenarios combine Shared Socioeconomic Pathways (SSPs) with Representative Concentration Pathways (RCPs) to explore how societal choices impact climate outcomes. As illustrated in Figure 66, the SSPs (shown on the horizontal axis) represent possible future changes in demographics, economics, technology, energy and land use, ranging from sustainable futures to scenarios characterised by regional rivalry or predominant fossil fuel development. Meanwhile, the RCPs (shown on the vertical axis) depict trajectories of greenhouse gas concentrations and radiate forcing levels by the year 2100, varying from very low emissions (1.9 W/m²) to very high emissions (8.5 W/m²).

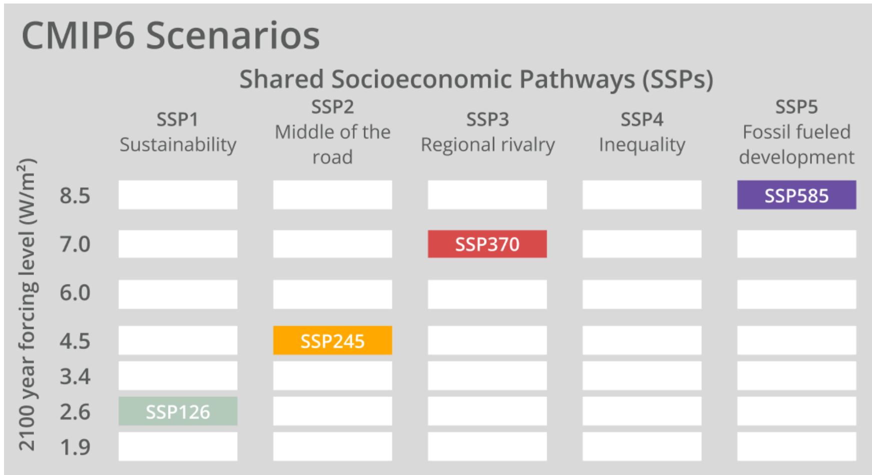


Figure 66. CMIP6 scenarios as combination of SSPs and RCPs

The climate variables (temperature and solar radiation) for each climate change scenarios are obtained from Copernicus C3S. Data from five climate models were selected and downloaded for each of the scenarios that will be available to the user (SSP245, SSP370 and SSP585). These data provide information on a daily basis for the timeframe 1985-2100 covering the historical (1985-2014) and the future period (2024-2100). For the future, data will be used in fixes time frames (sort, medium and long-term) and aggregated in a reference year for the use in the service: 2030 as a benchmark year for many European policies and targets (period 2024-2030), 2040 as a medium-term year (period 2031-2040), and 2050 as a longer-term year) (period 2041-2050). This adds up a total of nine scenarios of climate variables that will be pre-loaded into the service so that they can be visualise and compared with the baseline (current) scenario.

From these scenarios, three of them, the most representative ones (and different from the baseline) have been selected to be estimated in Service 3 to see how they impact the energy demand of the building stock. The following are the selected scenarios, together with the description that will be also available in the web tool:

- **SSP245 "not too bad scenario"**: it is the combination of **SSP2** (Shared Socioeconomic Pathway 2, "Middle of the road") and **RCP4.5** (Representative Concentration Pathway 4.5, intermediate scenario with a "not too bad" baseline). SSP2, medium pathway, extrapolates the past and current global development into the future. Income trends in different countries are diverging significantly. There is a certain cooperation between states, but it is barely expanded. Global population growth is moderate, levelling off in the second half of the century. Environmental systems are facing a certain degradation. SSP245 includes an additional radiative forcing of 4.5 W/m² by the year 2100, which represents the medium pathway of future greenhouse gas emissions. This scenario assumes that climate protection measures are being taken.

- **SSP370 "upper-middle part scenario"**: it is a combination of **SSP3** (Shared Socioeconomic Pathway 3, "Regional Rivalry") and **RCP7.0** (Representative Concentration Pathway 7.0, a high emissions scenario with a "upper-middle part" characteristics). SSP3 depicts a fragmented world with regional conflicts and a focus on security and defence over sustainability. Nationalism and competition among regions prevail, leading to limited cooperation on global issues. Economic growth is uneven, with some regions developing more rapidly than others, but overall global progress is stunted. Population growth is high in developing regions, exacerbating resource scarcity and environmental degradation. SSP370 includes an additional radiative forcing of 7.0 W/m² by the year 2100, reflecting high future gas emissions. This scenario assumes limited climate action and high reliance on fossil fuels, leading to significant climate impacts.
- **SSP585 "upper boundary of the range scenario"**: it is a combination of **SSP5** (Shared Socioeconomic Pathway 5, "Fossil-fuelled Development") and **RCP8.5** (Representative Concentration Pathway 8.5, a very high emissions scenario with "upper boundary" characteristics). SPP5 envisions a world focused on rapid economic growth and technological advancement, driven by intensive use of fossil fuels. This pathway prioritises economic development over environmental protection, leading to substantial increases in greenhouse gas emissions. Population growth is moderate, but economic and technological developments are rapid, especially in energy-intensive industries. Environmental policies are minimal, resulting in significant degradation of natural ecosystems. SSP585 includes an additional radiative forcing of 8.5 W/m² by the year 2100, representing the highest pathway of future greenhouse gas emissions. This scenario assumes minimal climate mitigation efforts and continued high dependence on fossil fuels, leading to severe climate impacts.

Once the climate data from these scenarios are obtained from Copernicus, the selected variables (e.g. temperature) are subject of a downscaling process using statistical methods. This method is a Quantile Mapping (QM) supported by a bias-correction of the extreme values. The QM method is motivated by the need to characterize the systems over the entire distribution of the climate variable, which makes it improve the estimates obtained with other simpler methods. It uses the quantile-quantile relationship to converge the distribution function of the simulated variables to the observed one and thus obtain the corrected climate variables for the future scenario under analysis. For this process, a set of 30 years of historical data of the weather stations are required. As a result, daily timeseries in the future will be obtained and transformed into hourly series following the distribution of typical meteorological years. Finally, the temperature data are included into the calculation algorithm to estimate again the energy demand and consumption under these climate change scenarios.

In this link (**https://tools.cartif.es/built-climate-scenarios**) the service can be accessed, with this temporary user (buildspace-SE3@cartif.es) and password (builDSpaceSE3_2024). The link may at times be inoperative, as work on the service and this application is still ongoing towards the final technical release.

As the integration of the solar PV potential function will only arrive at the final technology release, this is offered now in a different link (following paragraph). Following the first technological release methodology (1st Technological Release: Solar Map of Riga, Latvia (arcgis.com)), the development of PV potential has been extended for the whole city of Riga. Building footprints, as well as cadastral data and Digital Surface Models (DSM) where provided by the municipality of Riga and were implemented for the creation of an interactive PV potential map for the whole city. As in the first release, unsuitable parts of the rooftops were excluded, such as North faced parts of rooftops and steep slopes (>45 degrees), while the standard overcast sky model was used for solar radiation simulation. Diffuse and Transmittivity ratios were calculated from official sources, such as Global Solar Atlas and PVGIS, for the whole city of Riga. In addition, the municipality of Riga provided information regarding mean cost of installation of PV modules in Riga, as well as potential limitations in terms of installation.

The user can explore the different buildings of Riga, with access to basic cadastral information, such as building age (time of construction), use and type, as well as the PV potential in terms of MWh/year. The interactive map is accessible through the following link: Buildspace Solar Map (arcgis.com).

4.5. Next steps

The immediate next step is to properly present the results of the second release to the Riga Pilot. Firstly, it is important to showcase the results of the calculations for both the energy demand of the whole residential building stock with them, as well as the results of the calculation of the solar PV potential in the rooftops of the building stock, together with their suitability. Secondly, it is important also that the end-users test the web tool (first version of the GUI) to see if it is easy-to-use, intuitive and user-friendly enough. This is important because this service is not only targeted at urban stakeholders and decision-makers that have at least some expertise or idea on the topic, but also to citizens, such as building owners and residents.

In addition, to finalise the service towards the third and last technology release, these are the remaining steps that will be carried out:

- Development of the function for comparing selected climate change scenarios with the baseline one.
- Development of the catalogue of the retrofitting measures.
- Definition of KPIs to calculate retrofitting strategy gains, prepared to be calculated depending on the different characteristics of the building selected.
- Integrate this retrofitting strategies functionality in the front-end.
- Integrate the solar PV potential map and functions in the front-end.
- Integrate both the retrofitting strategies scenarios with the output of the solar PV potential of the buildings, to be able to assess what part of the demand and consumption is covered through the PV production (self-consumption).
- Integration of the service into the BUILDSPACE platform to be accessible through it.

5. BUILDSPACE services at city scale: Urban Heat Analysis and Resilience

The Urban Heat Analysis and Resilience (SE4) service addresses the increasing concern over urban heat and its social and environmental impacts. It is designed to assess urban heat risk at high spatial resolution by combining heat exposure data with demographic and socio-economic indicators. This enables the evaluation of social vulnerability to heat, highlighting which sections of the urban population are at greatest risk due to factors such as economic status, education levels, household composition, etc. The service also focuses on the Urban Heat Island (UHI) effect and other microclimatic phenomena, assessing their impact on the energy performance of buildings and supporting climate adaptation and mitigation strategies for urban stakeholders.

The service is designed with replicability across European cities in mind, using open data sources and flexible methodologies to ensure broad applicability.

5.1. Input and output

The inputs required for the Urban Heat Analysis and Resilience service include:

- Statistical georeferenced socio-economic and demographic data to assess vulnerability at district level.
- Data from citizen weather stations to assess the urban heat distribution and intensity within the city.
- Buildings' geometry (boundary and area, façade and party walls area), year of construction, height, buildings' use and/or typology and other building characteristics provided by the pilot and complemented with OpenStreetMap database.
- **Datasets obtained from Copernicus services:**
    - Satellite-derived geospatial data, Normalized Difference Vegetation Index (NDVI), and high-resolution RGB bands for land use and urban surface mapping.
    - Digital Elevation Model (DEM) that represents the surface of the Earth including buildings, infrastructure and vegetation.
    - CORINE Land Cover for the classification of land into different land-use categories such as urban areas, forests, agricultural areas and wetlands.
    - ERA5 global climate reanalysis data

The outputs generated by the service include:

- **Urban Heat Risk (UHR) map** – A high-resolution georeferenced map displaying areas of Urban Heat Risk, combining urban heat hazard, exposure, and vulnerability. This map helps identify priority areas for intervention.
- **Urban heat hazard map** – A high-resolution georeferenced map with the distribution of the urban heat and its intensity.

- **Urban Heat Vulnerability (UHV) map** – Displays socio-economic and demographic vulnerability to heat, considering the ability of communities to adapt to high temperatures.
- **Urban Heat Exposure (UHE) map** – Represents the areas most exposed to high temperatures, considering the most populated areas.
- **Buildings' energy demand**: Estimation and visualisation of the energy demand of the city buildings' stock
- **Decision support tool**: A selection of solutions for mitigation and adaptation to urban heat and identification of potential areas for intervention per solution.
- **Creation of long temporal series** of temperature and relative humidity to improve the urban assessment (e.g. weather files for the evaluation of energy performance of buildings).

The service allows users to interact with the maps, select different climate scenarios, and focus on specific areas of interest. These outputs are crucial for evaluating the resilience to heat, the impact of urban heat on energy demand and for guiding targeted adaptation and mitigation efforts.

5.2. User experience

The Urban Heat Analysis and Resilience service offers a decision support tool for various user groups, including:

- Policy makers and urban planners, who can identify urban heat hotspots and social vulnerability to heat, to prioritise areas of intervention and guiding their climate adaptation and mitigation efforts at both neighbourhood and building scales, e.g.:
    - countermeasures at municipal level, for days of extreme heat;
    - policy for opening public buildings as climate shelters;
    - policy for municipal buildings retrofitting for decreasing energy demand;
    - prioritise assistance to vulnerable people during extreme heat days;
    - policy at municipal level for assisting the residents of the most energy demanding buildings to apply for national funding).
- Scientists and urban researchers, who can use the service to investigate the effects of urban heat on local climates and communities and compare these findings across European cities. Furthermore, they can download weather files to be used in building energy models' simulations.
- Citizens, who can explore the heat vulnerability of their neighbourhoods and consider practical adaptation solutions (e.g., tree planting, cool roofs) to mitigate heat risks.
- Provision for consultancies and other areas for the use of specific weather files and buildings energy demand assessment.

The user experience through the SE4 application has been designed based on the workflow proposed, differentiating available functionalities based on whether the user is logged in or not (Figure 67).

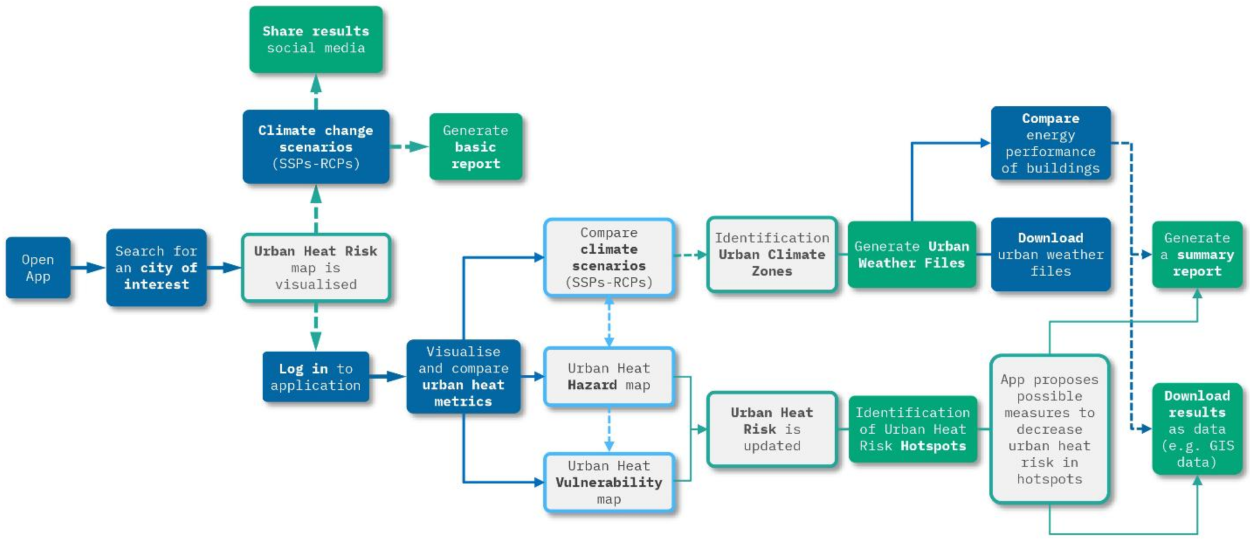


Figure 67. SE4 workflow from the user perspective

SE4 web application

When accessing for the first time, a welcome window appears on the screen giving the user the option to access the application directly or to follow a guided tour (Figure 68). Depending on the type of user registered, the data displayed and the application functionalities will be limited. By default, some basic data will be available in such a way that the user can explore what the service can offer.

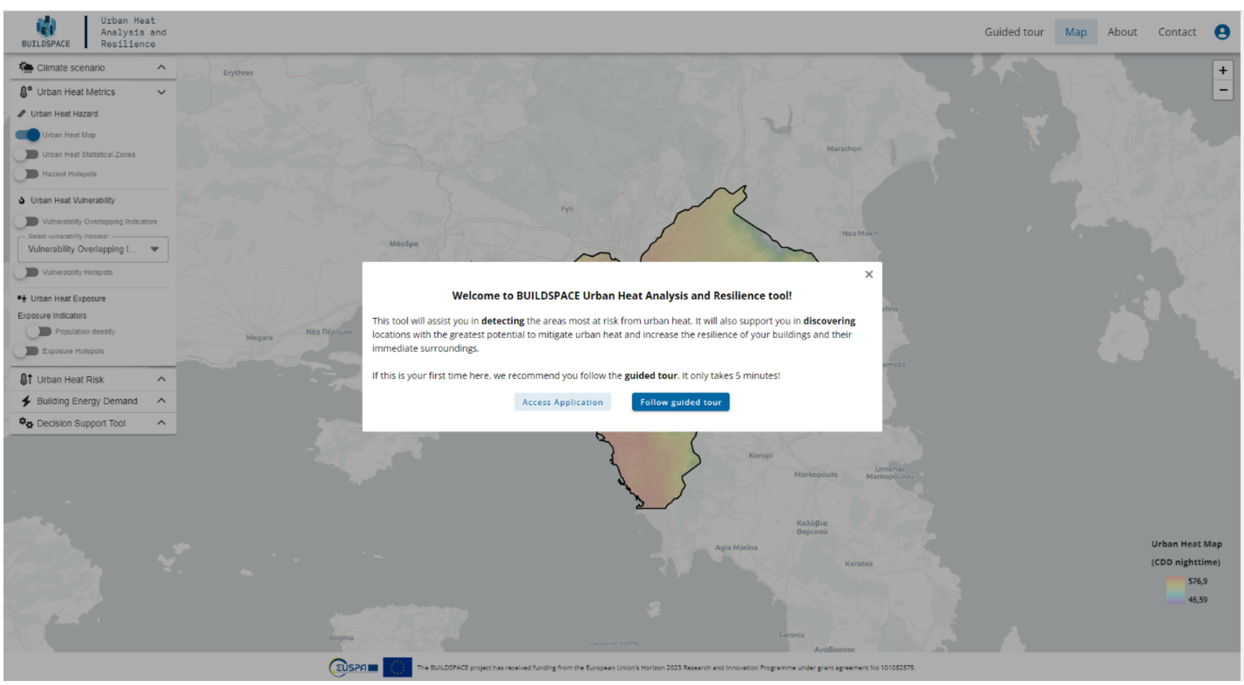


Figure 68. SE4 application welcome window

All data is listed at the left in a drop-down menu. First, the 'Urban Heat Metrics' contains the three determinants of Urban Heat Risk: Hazard, Vulnerability and Exposure. For the first one, an Urban Heat hazard high resolution interpolated map is displayed exhibiting the urban heat severity using CDD as a unit (Figure 69). The same information can be explored by census tract.

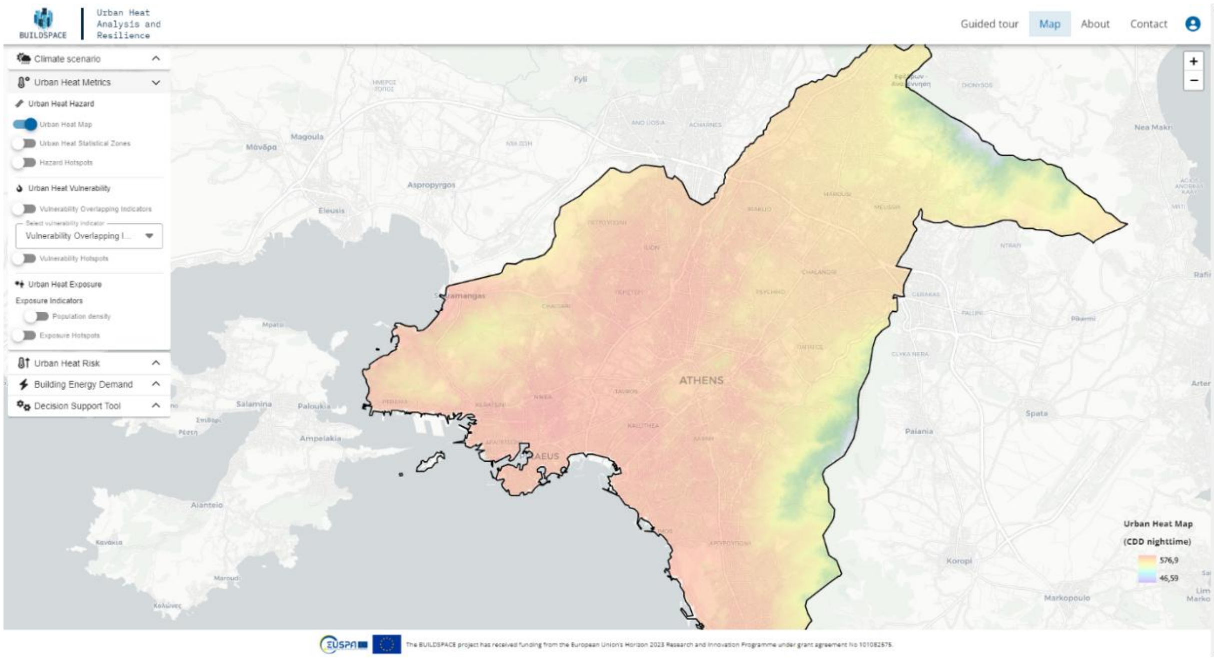


Figure 69. SE4 Urban Heat map, Athens metropolitan area

For the exposure, the available data go down to the municipal level of Piraeus, and the user needs to activate the population density toggle in the tool, to review where the census districts with the highest concentration of people are located (Figure 70). When hovering the mouse over a census tract, the user can retrieve statistical information.

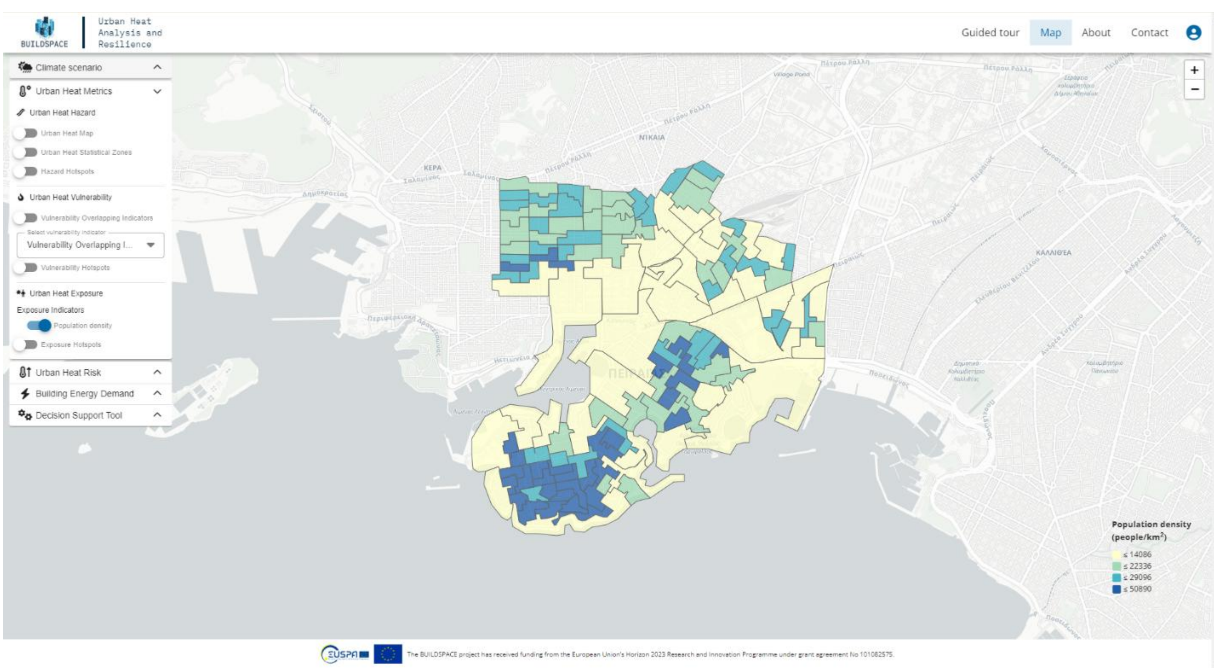


Figure 70. SE4 Exposure: Piraeus' population density

The vulnerability section collects information on the socio-economic and demographic indicators that are in the fourth quartile, also showing the areas where they overlap (Figure 71). The user has the option to select each of these indicators separately and display them on the map. In this way, the most vulnerable population can be characterised by census district. By hovering the mouse over the census tracts, statistical information can be retrieved.

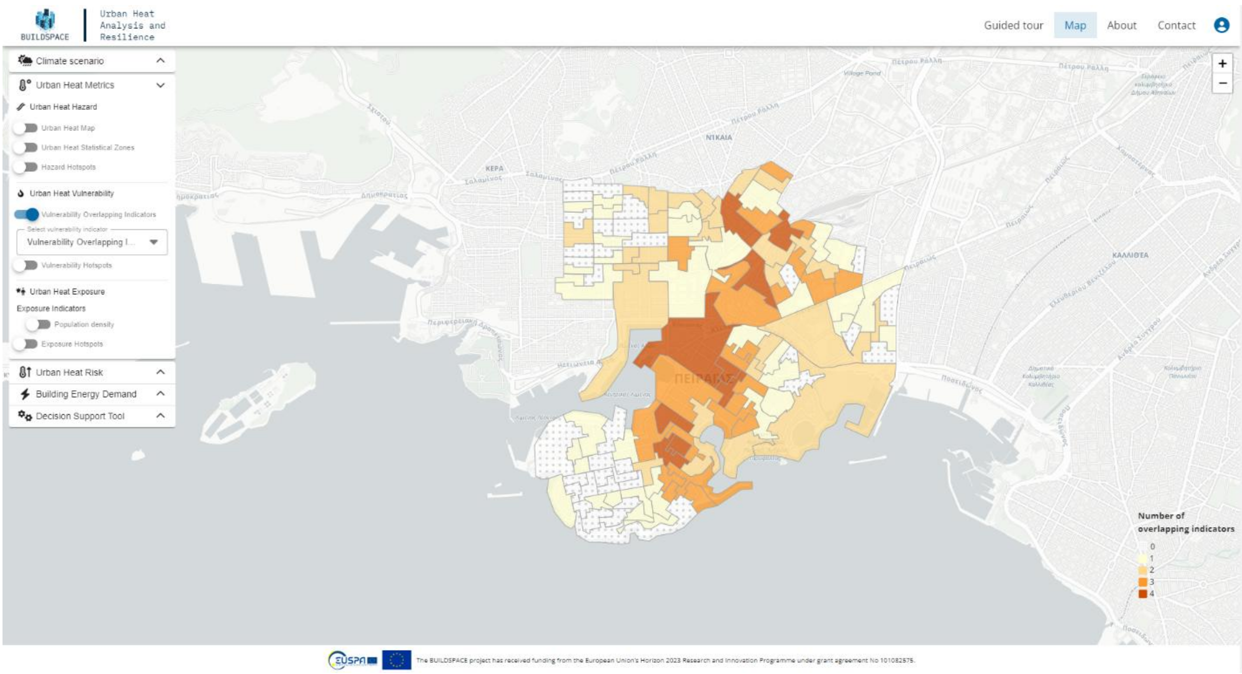


Figure 71. SE4 Number of overlapping vulnerability indicators

Additionally, for each one of these sections, hotspots are provided. The user can activate each hotspot and see how they overlap within the municipality of Piraeus (Figure 72).

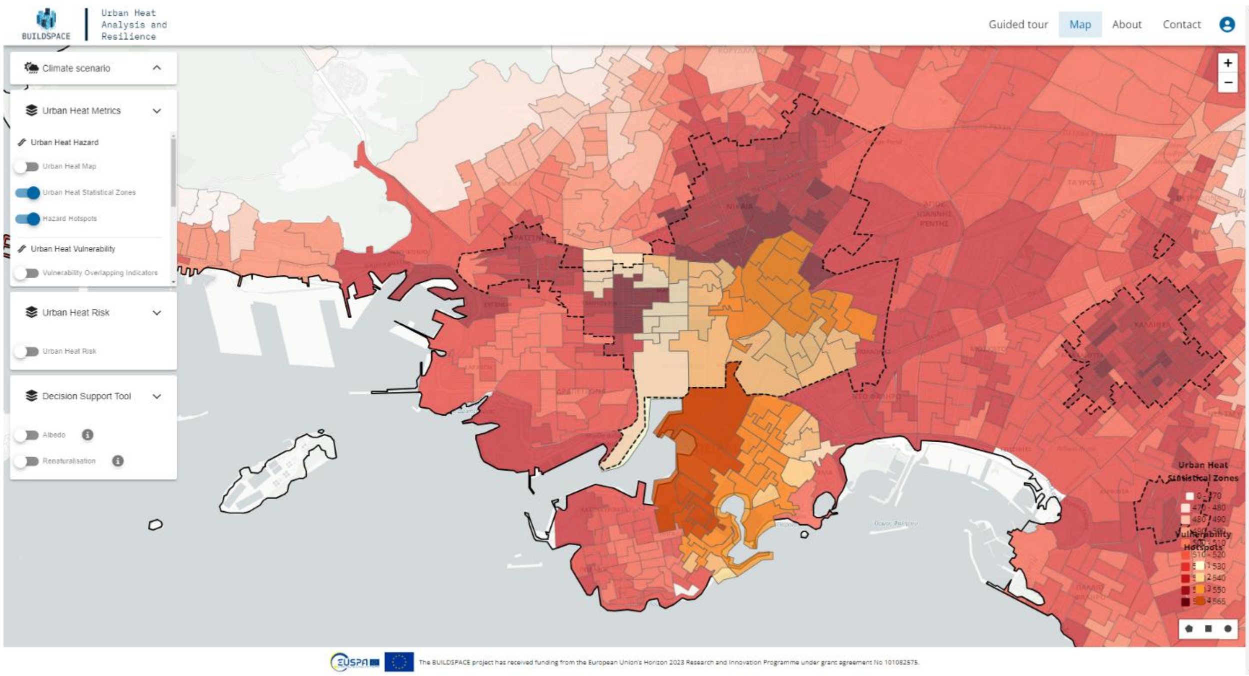


Figure 72. SE4 Intersection between hazard and vulnerability hotspots.

Next, the Urban Heat Risk map can be selected (Figure 73). This map is constructed from the previous hotspots (hazard, vulnerability and exposure). When hovering the mouse over the census tract, statistical information can be retrieved. If the user clicks on one of them, the top tab emerges with the statistical information of the indicators displayed in graphs and tables (Figure 74). This functionality contributes to better understand the factors that contribute the most to the risk level.

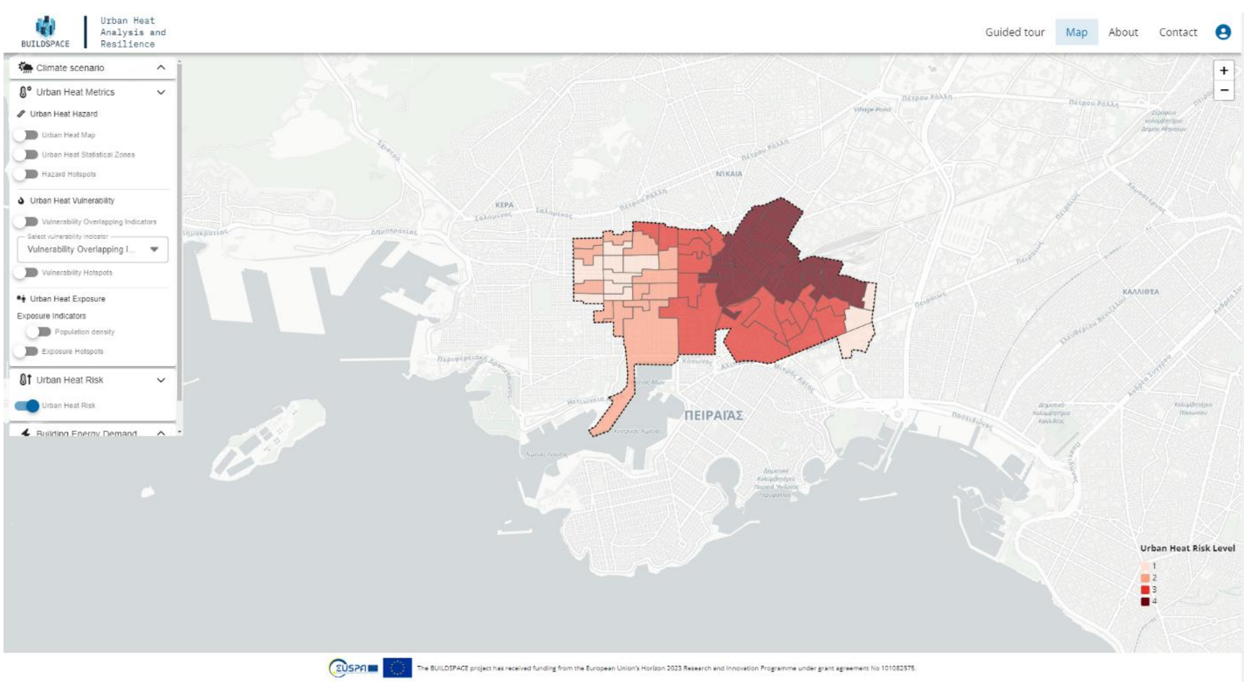


Figure 73. SE4 Urban Heat Risk map

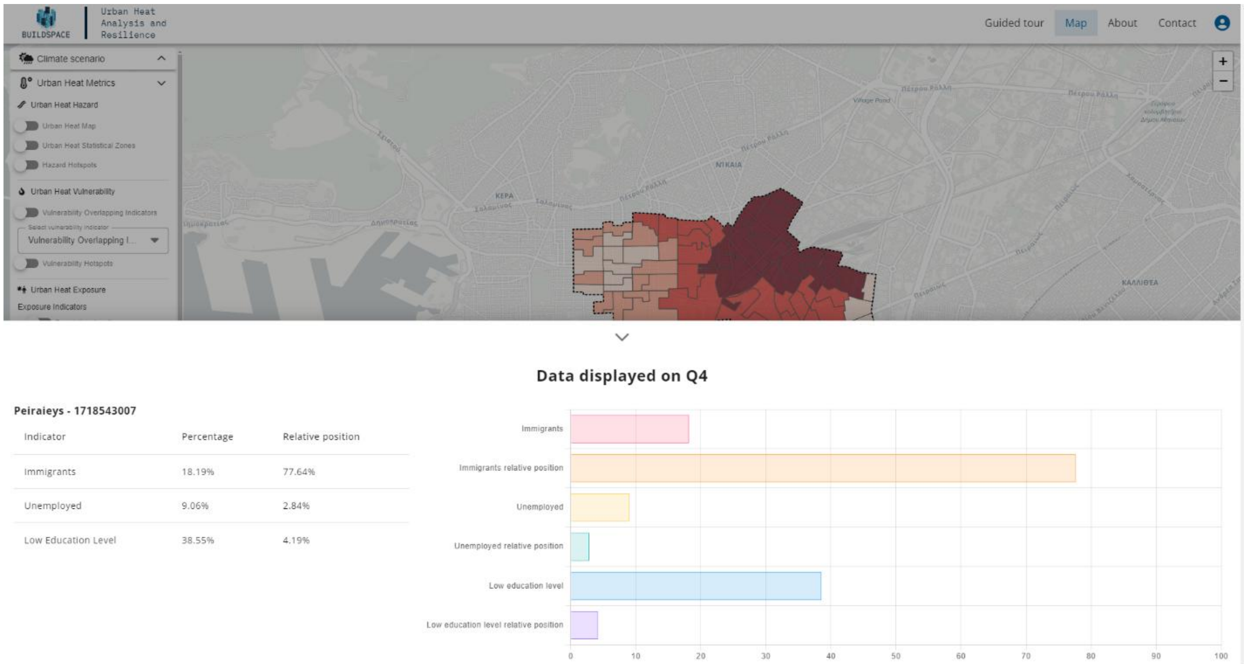


Figure 74. SE4 Statistical information for a census tract within the Urban Heat Risk delimitation

Now, the user can also explore the buildings' energy demand within the municipality of Piraeus (Figure 75). This analysis is available for both cooling and heating demand. Using the colour palette of the legend as a guide, the user can easily identify those buildings that have a higher energy demand while contrasting the result with the areas at higher risk of urban heat.

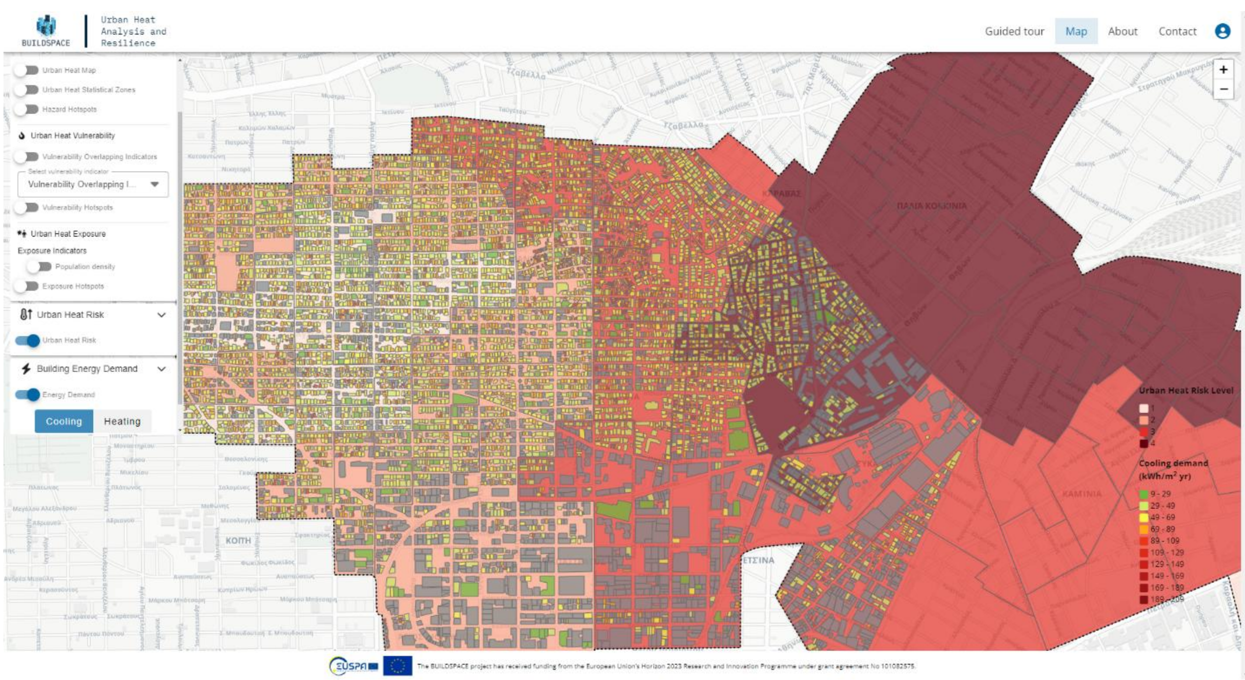


Figure 75. SE4 Buildings' energy demand overlapping Urban Heat Risk map

Finally, the first version of the decision support tool is included (Figure 76). In this section, the user can explore two possible solutions for the mitigation and adaptation to urban heat: albedo and re-naturalisation of spaces. An information icon is next to the layers to provide more detail insights regarding the solutions: why are they important to be considered, how they can be applied and the particular situation of the municipality of Piraeus. The data is displayed in a way that the user can easily identify which are the potential areas of intervention.

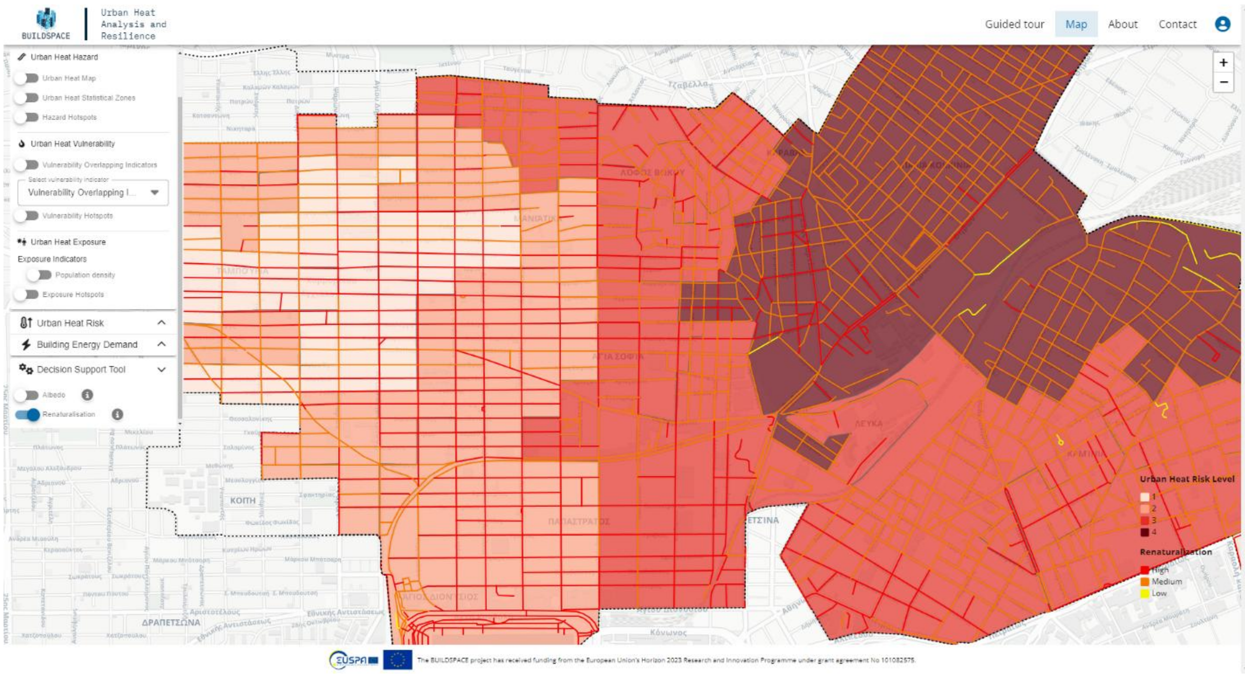


Figure 76. SE4 Decision support tool: Potential areas for re-naturalisation by priority level. Background map: Urban Heat Risk

5.3. Application to pilot and replication potential

This service is currently being developed and tested in Piraeus (Pilot 3), one of the largest urban municipalities in Greece. The service builds on existing datasets to provide high-resolution urban heat analysis and vulnerability mapping. This integration of conventional and unconventional data sources aims to deliver a more accurate representation of urban heat hazards and their socio-economic impacts in the city.

One of the main interests of the pilot is to be able to visualise the distribution of urban heat in the municipality and to identify those areas most at risk where vulnerability and exposure variables come into play. Throughout the development and implementation of the service, meetings have been held to review the data and results obtained between the pilot partner and technical partners. In particular, receiving feedback on the consistency of the vulnerability indicators in order to detect possible inaccuracies in the development of the methodology and providing information on the databases to be used.

Replicability considerations for the SE4

From the outset, the development of SE4 has been designed with replicability across other European cities in focus. To this end, in its initial phase, an extensive exploration of open and standardised databases at European level was carried out, from which the service can be provided.

In this exploration, criteria were established that these databases had to meet to be integrated into the workflow:

1. **European scale**: the databases should provide information on European cities.
2. **Open data sources**: Collection of data that are freely accessible to the public allowing to view, use and share the data.
3. **Spatial resolution**: High spatial resolution is required to provide more precise analysis within the cities.
4. **Standardized format**: To facilitate easy access and interoperability with other data sources.
5. **Time frame**: Data needs to be as up to date as possible to obtain an analysis that is representative of the current context.

By leveraging satellite imagery, citizen weather station data, and socio-economic indicators, the service can be customised for cities with varying levels of data availability. In this respect, the use of data from citizen weather stations allows and ensures the development of urban heat analysis on a European scale, achieving a non-reliance on conventional meteorological networks.

One of the major limitations is the existence of open and standardised databases at the European level for the collection of socio-economic and demographic data at a spatial resolution that allows analysis at the census tract level for the vulnerability assessment. For this reason, a list of possible indicators has been established with which the analysis can be developed, allowing for flexibility according to the availability of data.

For the estimation of the energy demand in Piraeus pilot, which is actually already a replication of the SE3 main feature (section 4), there are several limitations in the original data provided by the Greek pilot. These limitations affect the overall accuracy and completeness of the energy demand estimation for Piraeus, requiring careful consideration in the replication of the service. Some of these limitations are:

- **Erroneous data entries**: some columns contained inconsistent or erroneous values, such as *#REF!*, or the columns name are not auto-explicative. These issues required renaming the columns and correcting the erroneous values.
- **Inconsistent data entries**: a major limitation in the original dataset involved inconsistencies in categorical fields like *building_condition* and *BuildingUseKindId*. For example, the term "*Κακή*" (meaning "bad" in Greek) appears with variations such as "*κακή*" (lowercase), "*ΚακΉ*" (with different letter cases), or even with minor typographical errors. Ranges like "*1950–1986*" also had to be standardised to "*1950-1985*". These inconsistencies, likely due to manual data entry, hinder data analysis because equivalent values are stored differently.

- **Duplicated IDs**: the dataset includes duplicate IDs in the *CODE* field. These new unique IDs were generated, some duplicate records might remain unidentified and unresolved.
- **Temporal inconsistencies**: the data spans different years (e.g., 2018, 2020, etc.), which creates discrepancies when merging datasets from various periods.
- **Imprecise construction year ranges**: the year-of-construction ranges are too broad: “before 1920”, “1920-1950”, “1950-1985”, and “more than 1985”. This creates challenges in accurately characterising buildings, as, for instance, a new building from 2023 is categorised together with one from 1985. Selecting a representative year from these ranges is difficult, and often not reflective of the building’s actual age.
- **Incomplete or missing data**: several fields, such as *BuildingExploitYear*, *BuildingGroundFloors*, and *BuildingUseKindId*, have missing values (*NaN*). To address this, predefined defaults are used (e.g., using “1975” for missing *BuildingExploitYear* values, or 'Κατοικία' for missing BuildingUseKindId), though this could lead to inaccuracies if not carefully managed.
- **Erroneous geometries**: the building geometries are not always accurate. To address this, data was cross-referenced with OpenStreetMap, an open-source tool that provides more detailed spatial data. However, OpenStreetMap does not fully cover the Piraeus region, leaving some areas with unresolved inaccuracies.

5.4. Technical development update: second technology release

The second technology release of the Urban Heat Analysis and Resilience service focuses on improving the resolution, accuracy, and functionality of the heat risk analysis while integrating feedback from the pilot users. The following key advancements have been made:

- **Hazard assessment:**

For this release, three high resolution maps have been obtained to gain a deeper understanding of the distribution and intensity of urban heat at the Athens metropolitan scale. First, an analysis was performed at the Athens metropolitan scale using interpolation techniques of the data obtained from the CWS displaying information regarding the CDDs. Then, through a zonal statistical calculation, the distribution by census tract was obtained. Finally, hotspots were derived from which one of them is situated within the municipality of Piraeus.

- **Vulnerability assessment:**

A thorough review of the scientific literature has led to the selection and refinement of urban heat vulnerability indicators. In this release, demographic data (e.g., percentage of female residents, unemployment rates, percentage of low education levels, and percentage of single-person households etc.) has been processed into high-resolution georeferenced layers at district level. These indicators are used to calculate the Urban Heat Vulnerability (UHV) preliminary map, which now provides a more nuanced assessment of social vulnerability to heat. The integration of these new datasets allows for the identification of urban areas with the highest risk based on socio-economic conditions, enabling more targeted adaptation strategies.

- **Exposure assessment:**

In line with the concepts of the latest IPCC report, indicators were identified that can be used to analyse heat exposure in a given area. Then, the data available for the pilot was verified, which for this second technology release was only possible with the indicator of population density. From this layer, hotspots within the municipality were obtained which were then used to calculate urban heat risk.

- **Improved user interface and data visualisation tools:**

The user interface has been enhanced to offer a more intuitive experience. Users can now interact with detailed heat maps, including the Urban Heat Risk, Hazard, Exposure, and Vulnerability layers for the current climate scenario. A decision support tool has been introduced, allowing users to identify potential areas where to implement mitigation and adaptation solutions, within the urban heat risk delimitation. Additionally, it provides a summary analysis for the city current situation.

- **Refined energy profile integration:**

As replication of the BUILDSPACE SE3, the second release integrates detailed energy performance profiles of buildings in the Piraeus, to see the cooling and heating energy demand of the residential buildings for the whole city (despite the limitations due to data covered in previous section).

- **Replication and scalability enhancements:**

To facilitate scalability across European cities, the system has been optimised to handle different datasets, including those from open data sources such as Copernicus, and national cadastres. Scripts have been developed to standardise the data processing workflows, ensuring that the service can be easily adapted to different cities without extensive reconfiguration. These enhancements support the goal of making the service replicable and applicable across diverse urban environments in Europe.

The preliminary results from the SE4 can be accessed in the link: **https://buildspace-s4.web.app/**

5.5. Next steps

The focus for the third and final technology release will include:

- Final validation with Piraeus pilot partners to ensure the accuracy and usability of the service, including testing the vulnerability indicators and usage of the SE4 application.
- Final maps for vulnerability, exposure, hazard and risk assessment.
- Creation of long temporal series of temperature and relative humidity.

- Refinement of the climate scenario comparison tool, allowing for a broader range of future climate projections.
- Further improvements in the data visualisation and reporting functionalities, enabling users to generate detailed reports tailored to their specific needs.
- Enhancement of the decision support tool.
- Validation of the energy demand in residential buildings and find more accurate data to address some of the data limitations found at the current stage.

6. BUILDSPACE services at city scale: Urban Flood Analysis and Resilience

The Urban Flood Analysis and Resilience service (SE5) aims to calculate and visualise **expected flood damage** to building stock and **flood vulnerability hotspots with hydrological impacts of blue-green infrastructure (BGI)**. It provides calculations and visualisations for the future according to different climate-driven scenarios in accordance with the widely accepted RCPs.

In this way, SE5 will provide a decision support service to assist urban stakeholders in planning for the maintenance and retrofitting of the building stock against the risk of climate change, using simplified models to better analyse the benefits or value of interventions, considering the effects of climate change.

The service will be operated by a user-friendly web tool with a coloured map and different types of graphs as the basis for delivering the information in a very visual and easy-to-use way.

6.1. Input and output

The **input data** required for the service is the following:

- **Buildings and infrastructure data:**
  - **Cadastral** national building data
  - **OpenStreetMap**
- High resolution raster images of the pilot area (orthophoto)
- **National administrative and urban planning data:**
  - Registry of spatial units (municipality boundaries)
  - Floods extend map
- **Copernicus satellite data:**
  - **CLMS** Urban Atlas

The **outputs** of the service are the estimation and visualisation of expected flood damages for several damage categories. The service provides visualisations in a coloured georeferenced map, tables and graphs, and offers visualisations for current and three climate change projections. In the scope of the service, by the final release, a catalogue of different BGI measures with condition instructions for building renovations will be created and at least three retrofitting scenarios will be available for the user to select and compare.

6.2. User experience

In the application developed for service 5, the target users can use simulated floods to calculate damages to different buildings and land use features. This allows policy makers and other stakeholders to visualize damage hotspots for potential flooding events. At the final technical release, a decision support system will be incorporated to support stakeholders by suggesting retrofitting BG-measures.

Figure 77 shows the workflow of the application in a summarized manner. After logging in, a user will select the Flood Damage Hotspots tool. As the effect of BGI is not taken into consideration yet, this step has been done automatically. Further, the user will define an area of interest and a climate scenario. The climate scenarios are now reflected in different statistical floods. When the user has selected an area of interest and a climate scenario, a damage hotspot layer is created. The user can visualise the damage layer on the map or use a data panel that give a summarized result in the form of graphs and tables. The exporting of the data in a report form has not been incorporated yet. All functionalities are described more in detail in the following paragraphs.

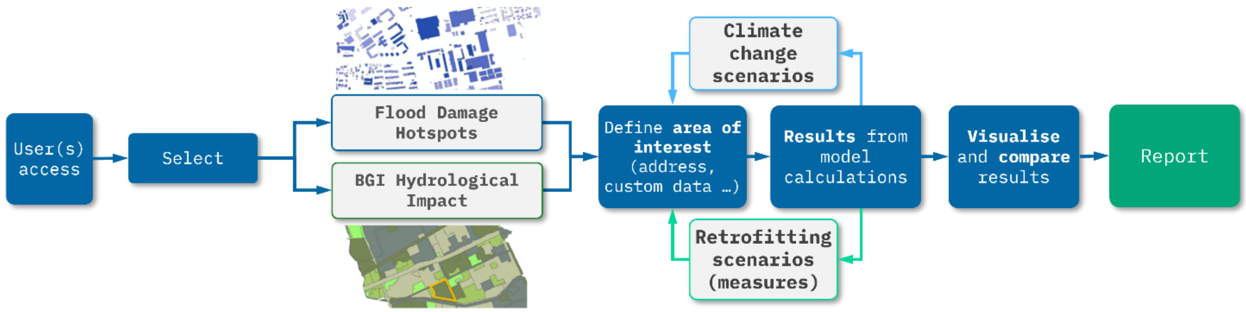


Figure 77. SE5 Urban Flood Analysis Resilience user experience (service workflow from user perspective)

Selecting a flood scenario

The user can select different flood scenarios and visualise them on the map. As can be seen in Figure 78, the user can choose a flood from three different return periods: 10-year, 100-year and 500-year. Beside the return period, he can also choose to simulate either climate change, which will expand the flood extent by 30m, or incorporating anti-flood measures, that will decrease the extent by 50m. When a user has chosen a desired flood scenario, the scenario will be used in the next damage calculation. The user can navigate the flood on the map.

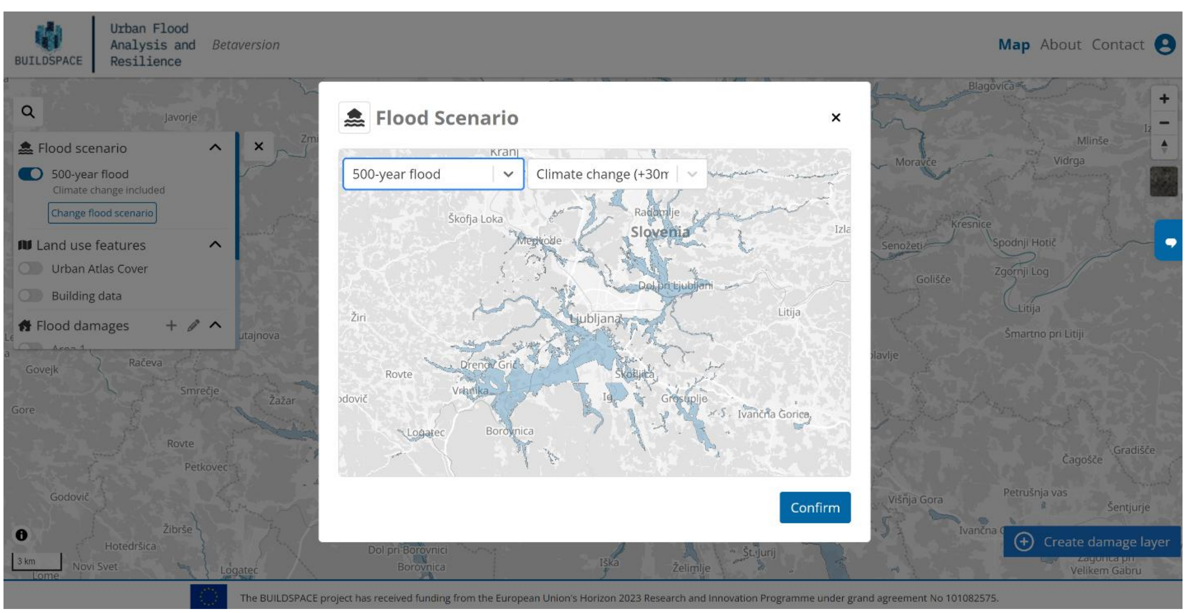


Figure 78. SE5 selection of a flood scenario

Selecting land use features

Besides the flood scenario, a use can also choose to focus on either buildings or on all land use features. For buildings, a pre-loaded building stock file of the Ljubljana Urban Region is provided. In the third technical release, a user will be able to upload their own building file through the core platform. For land use features, we opted for the Copernicus Urban Atlas Cover (UAC). This layer can be visualised on the map and an opacity slider allows the user to increase or decrease the opacity. This allows for overlaying the flood extent clearly. Figure 79 also shows the legend of the UAC, stipulating the large number of categories that can be taken into consideration when creating a damage layer.

Figure 79. SE5 selection of land use features (from the Urban Atlas Cover)

Creating an area of interest and a damage layer

By clicking the 'Create damage layer' button, a new screen opens (Figure 80). In this screen, the user can define all the necessary parameters to calculate a new damage layer. Besides providing a name, the user can also select a flood scenario. The scenario that is in use on the base map is selected here as a standard, but a user can still opt to change it. For UAC damage layers, a user can also define a flood height. The damage calculations will take this into account. Flood height is not yet taken into consideration when calculating a building damage layer. Further, a user can define an area of interest. Users can either use the dropdown to choose an area of interest they have drawn earlier or draw a new area of interest. When drawing an area of interest (Figure 81), the map will go into drawing mode. The user can use three different drawing modes to create an area. They can use either draw a circle, a rectangle or a free polygon. An area of interest can only be 1km² in size for computing reasons. The drawn area can be named by the user and is saved to the user's profile. When the area of interest is defined, the user final needs to define which land use features they would like to use. Either the user chooses buildings or features from the UAC. When choosing the latter, the user can also decide which specific classes that should be included or excluded in the calculations. Only classes that are located within the area of interest will be listed. When all parameters are set, the damage calculation will be computed and the results will be loaded.

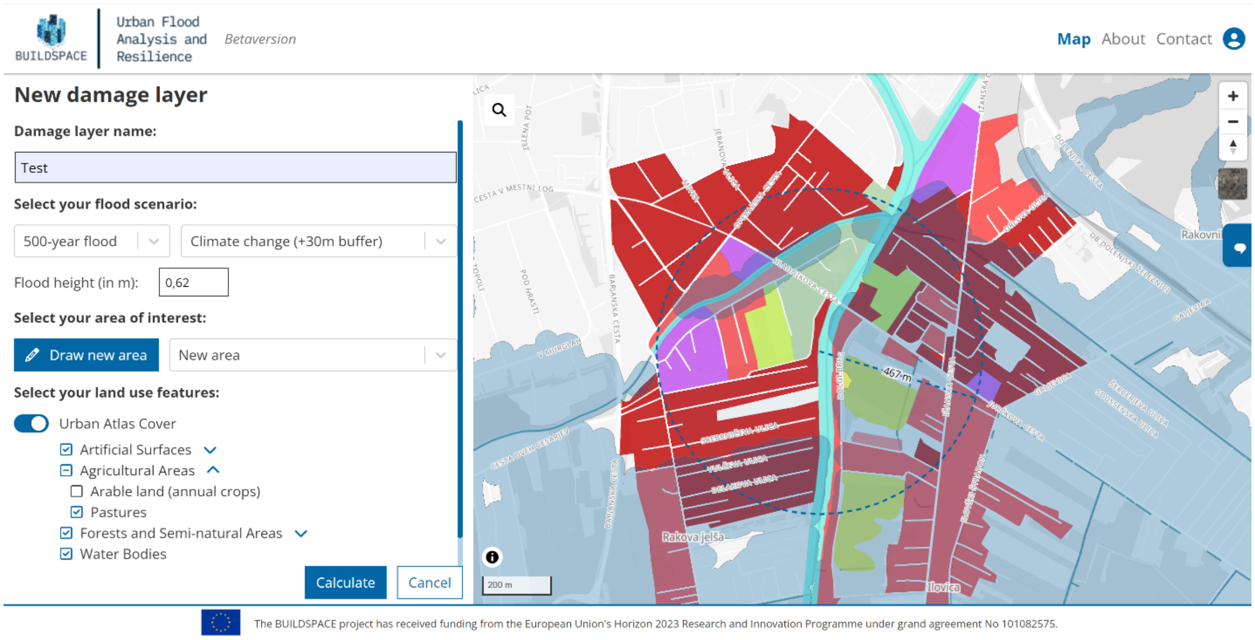


Figure 80. SE5 creation of a new damage layer

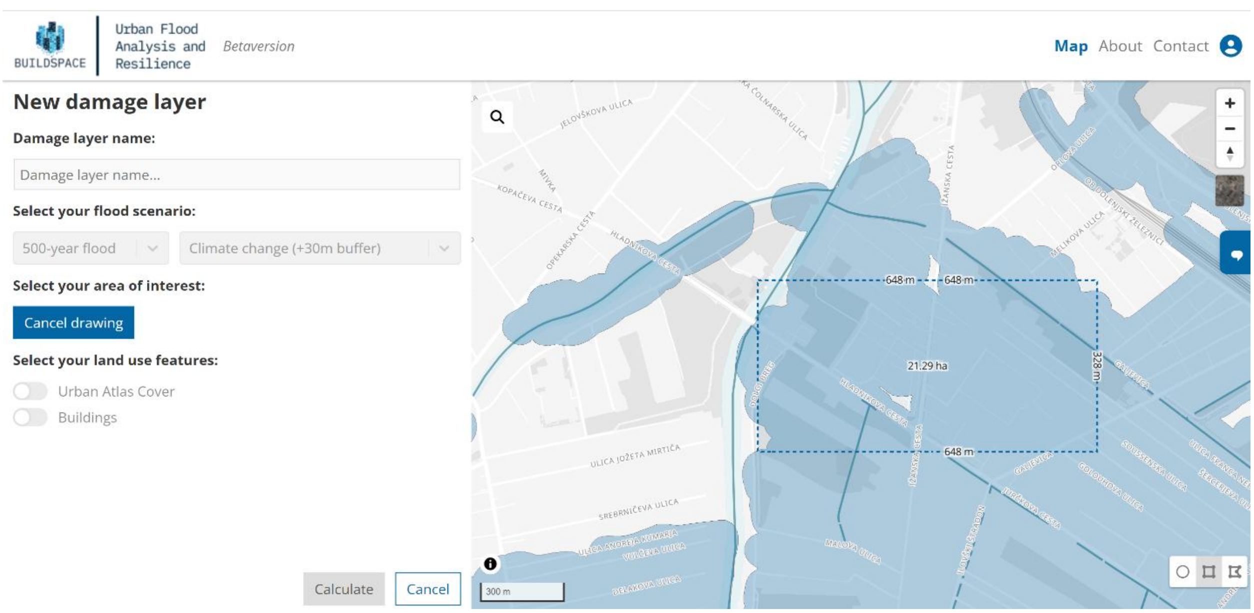


Figure 81. SE5 creation of a new damage layer: drawing the area of interest

Visualizing a damage layer

As portraited in Figure 82 and Figure 83, damage layers can be visualised on the map in two different manners. Firstly, there is a categorical visualisation where fixed categories have been used, ranging from low to very high. This allows for cross area comparisons as the classes are exactly the same for each created damage layer. Secondly, a user can also decide to use a continuous scale that is relative for this specific damage layer. This scale, which is always coloured red, will use the lowest value in the damage layer as the lightest shade of red and the highest as the darkest shade. This way, a user can clearly see the differences and nuances within the researched area.

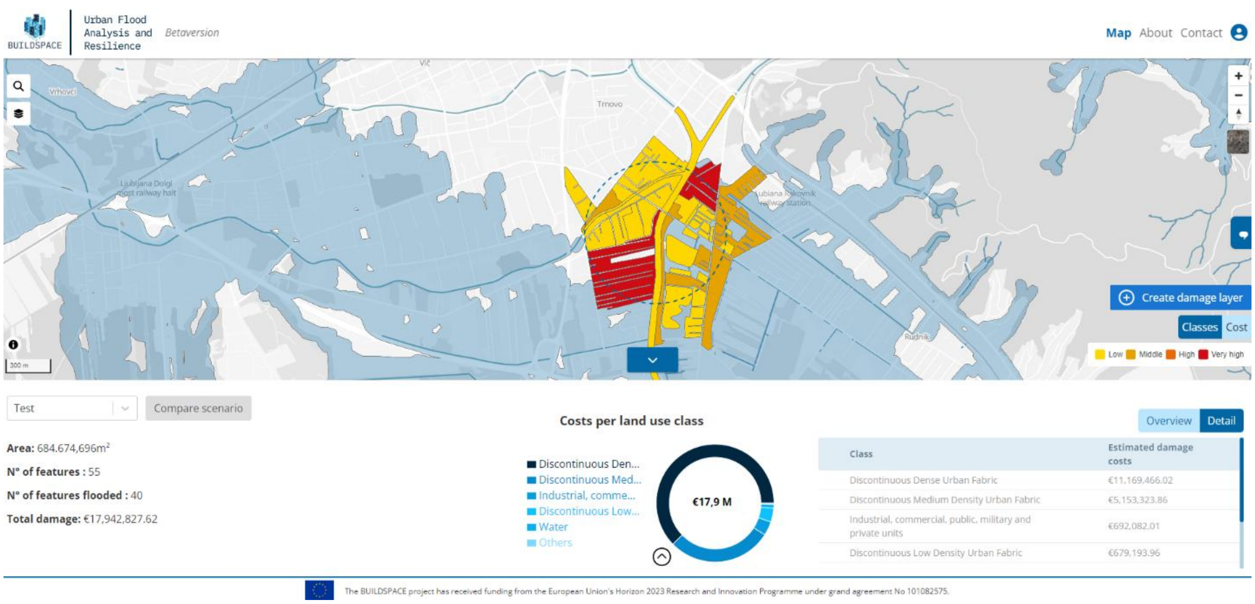


Figure 82. SE5 visualisation of damage layers: costs per land use class in the data panel and categorical visualisation on the map

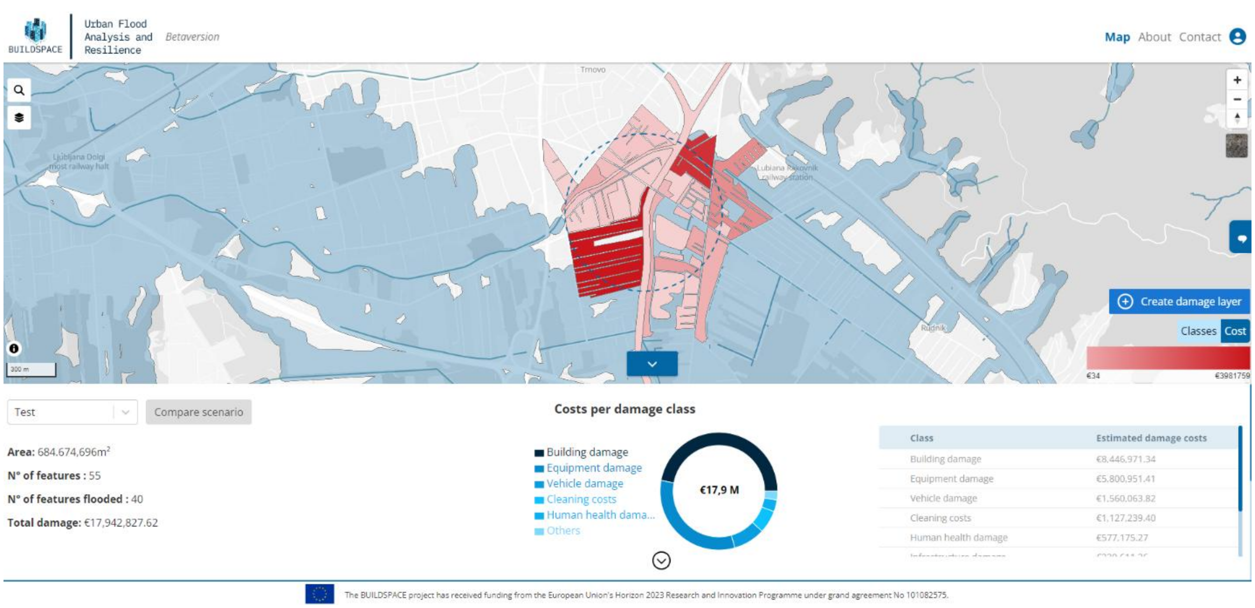


Figure 83. SE5 visualisation of damage layers: costs per damage class in the data panel and continuous visualisation on the map

The user can also open a data panel to better analyse the results. The data panel allows for different visualisations based on two result types. Firstly, when using the UAC as a source, the user can analyse the distribution of costs between the different land use classes. These results are represented both in a graph and a table. The user can use a toggle to switch between 'Overview'-mode, which shows the 5 major land use categories, or use the 'Detail'-mode which shows each sub-category independently. This type of visualisation is not applicable for building damages. Secondly, the data panel also demonstrates the results as a distribution of damage classes. For each flooded feature, different damage classes might be applicable. For example, most build-up areas can have damages to buildings, equipment, vehicles, people injuries and fatalities as well as cleaning costs. Some damage classes are only applicable to certain land use classes. Again, the distribution of the damage classes is shown in graph and table form.

Comparing two damage layers

To meet the needs of the target groups, a comparison tool was developed. Figure 84 shows the comparison of the damages predicted for a 100-year and a 500-year flood in the same area. At this moment, only comparisons within the same area are allowed. When a comparison is started, a user can decide which damage layers need to be compared. Both layers will be loaded into the map and a map slider will appear. The user can navigate the map slider from left to right to compare the two damage layers. The data panel shows a comparison both in table as in graph mode, e.g. calculating the increase or decrease of each damage class.

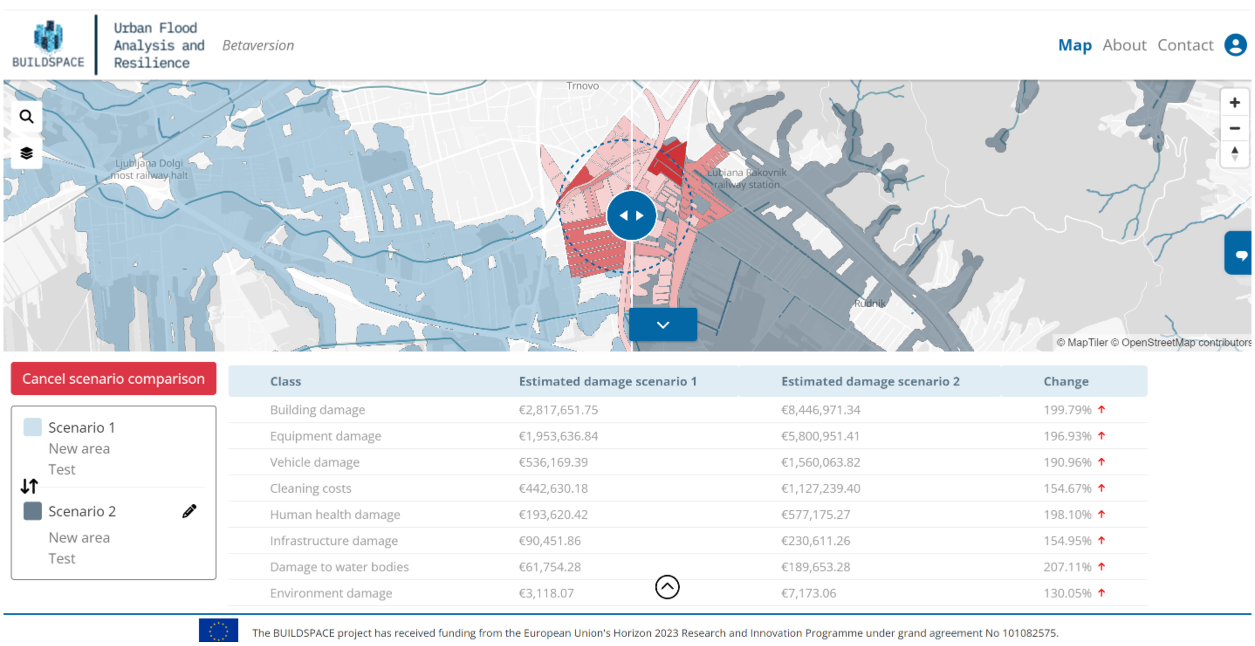


Figure 84. SE5 comparing two damage layers

6.3. Application to pilot and replication potential

This service is being developed and tested in Ljubljana Urban Area (Pilot 5), which is the largest urban area in Slovenia. Based on numerous interactions and discussions with key stakeholders, as well as their feedback from bilateral discussions and co-creation sessions, we have identified their specific interests in service's functionalities.

This information was the basis on which we built and adapted the service, functionalities and visualisation methods to best respond to end users' needs and wishes. The main requirements we addressed were:

- Selecting area of interest by polygons and by address
- Visualisation of the service in a map
- Results' visualisations by graphs and tables
- Retrofitting measures scenarios (still to be developed)
- Climate change scenarios by RCP projections
- Comparison mode for comparing different scenarios

The development of the service has been designed from the outset with both scalability and replicability in other European cities and beyond in mind. The general interest of urban stakeholders and citizens in European cities is that, despite the lack of results from hydraulic flood safety models due to the unavailability of detailed data, cities often lack ways to warn of their vulnerability to urban flooding, which is further increased by climate change. In addition, the service makes use of the considerable amount of open data and other commonly available databases in cities, which facilitates its adaptation to other areas.

To facilitate the replicability in other European cities, the inclusion of the Urban Atlas Cover (UAC) was an important step. The UAC provides detailed land use information for all urban areas in Europe with at least 50.000 inhabitants. As SE5 is connected to the APIs of this Copernicus product, the application is useable at all areas where the UAC has data. The only limit at this technical release, is that only pre-loaded floods for Slovenia are available. Nevertheless, with the development of the core platform, user will be able to upload their own flood extents, as well as their own building data, so that they can initiate a flood damage simulation at any desired location.

6.4. Technical development update: second technology release

The application has had some major updates since the first technical release. Most importantly, all calculations can now be done on the fly and the user can provide inputs for all parameters such as the flood extent, flood depth and land use features. To increase the replicability of the service, the connection to the Urban Atlas Cover is vital. This allows users to calculate damage layers for each urban area in Europe with at least 50.000 inhabitants. Furthermore, the data panel has been added since the first technical release, allowing users to closer analyse damage layers in different manners. In addition, all map visualisations such as the categorical and continuous scale were added to increase operability. The comparison mode, including the slider, were added to increase the impact of the tool as it allows users to easily compare different scenarios. The application can be consulted here: https://buildspace.nazkamapps.com/.

6.5. Next steps

To finalise the service towards the third and last technology release, these are the remaining steps that will be carried out:

- Final validation with some key stakeholders through the IMZI pilot partner to ensure the usability of the service for potential end users.
- Integrate blue-green infrastructure impact use case (UC5.2) and blue-green factor analyses in the front-end.
- Development of the catalogue of the retrofitting measures.
- Integrate this retrofitting strategies functionality in the front-end.
- Refinement of the climate scenario comparison tool, which provides three RCP future climate projections.
- Integration of the service into the BUILDSPACE core platform to be accessible through it.
- Allow users to upload/use custom flood extend and building data.

7. Progress made and next steps

Significant progress has been achieved in fulfilling objective 2 and objective 3 from the Grant Agreement, ensuring the development of a robust baseline infrastructure and interoperable framework for data integration, as well as the implementation of novel digital twin and city-level services to support urban resilience and climate adaptation strategies.

Progress on Objective 2:

O2: To build the baseline infrastructure and interoperable framework providing access to heterogeneous data sources to enable the development of location-based and remote sensing applications.

The BUILDSPACE **Core Platform** has been successfully designed and deployed, ensuring seamless integration of diverse data sources such as Copernicus data, EGNSS services, IoT data and sensor-based information. The first release of the platform was completed and documented in D3.1, while the second release, in the present document, introduces extended functionalities, including integration of Copernicus Land, Atmosphere and Climate change services. The platform now includes a user authentication system, REST API endpoints, and an SE-compatible storage system to enhance data management. Additionally, a frontend leveraging CKAN has been developed to provide an intuitive data visualisation experience. The integration of EGNSS Galileo HAS is currently in its finalisation stage.

The Core Platform development followed two major milestones: an initial release covering the infrastructure, authentication and storage components, followed by a second release integrating Copernicus/EGNSS data and user-friendly client libraries. Initial testing has been completed, with datasets from SE4 uploaded, and additional datasets will be made available upon the final release.

Progress on Objective 3:

O3: To develop novel services using Digital Twins to support building construction, renovation and monitoring and link them with city scale services enabling urban environment analysis, forecast and climate resilience.

The second technology release has successfully delivered an advanced version of the five BUILDSPACE services, making substantial progress towards the final iteration. Each service supports energy efficiency, climate resilience and urban-scale environmental analysis.

The **Digital Twin Generation (SE1)** service has advanced with the completion of point cloud model collection from pilot sites, enhancements in Scan2DT workflows, façade detection and as-built BIM comparison, and the integration of EGNSS data for accurate positioning. The **Digital Twin Enrichment (SE2)** service has finalised the RGB point cloud and thermal integration, enabling the identification of thermal bridges, cracks, dampness and malfunctioning solar panels. Additionally, interactive visualisations and automated reporting functionalities have been advanced.

At the city scale, the **Built Environment Climate Scenario (SE3)** service now provides a web-based energy demand visualisation tool covering the entire city residential building stock, incorporating climate change projections (SSP245, SSP370 and SSP585) and solar PV potential assessments. The **Urban Heat Analysis and Resilience (SE4)** service offers high-resolution urban heat maps, integrating socioeconomic vulnerability and climate exposure data, while the **Urban Flood Analysis and Resilience (SE5)** service now includes flood risk damage mapping based on statistical flood return periods and climate-driven hydrological modelling scenarios.

The second technology release has been completed as planned, aligning with the Milestone 6, which requested full functional implementation of the BUILDSPACE solutions. Testing and validation activities are ongoing, with refinements schedules ahead of the third release.

Next steps

The next phase of the project will focus on finalising the third and last technology release, ensuring full implementation, validation and replication potential for BUILDSPACE services.

For the **Core Platform**, efforts will be directed towards the finalisation of Copernicus and EGNSS integrations, expansion of dataset availability and deployment of enhanced search functionalities and UI improvements. The **building-scale services (SE1 and SE2)** will focus on improving DT visualisations (VR/AR and screen-mode), refining automated thermal anomaly detection, optimising Scan2DT workflows and increasing accuracy in construction monitoring tools.

At the **city scale (SE3, SE4 and SE5)**, the emphasis will be on integrating retrofitting strategies into SE3, enabling users to evaluate the impact of energy efficiency measures, while also refining climate change impact projections on urban heat (SE4) and flood risks (SE5), and finalising validation efforts to ensure their applicability in real-world urban planning scenarios.

To prepare for the final release, the replication strategy will focus on incorporating user feedback, ensuring validation across BUILDSPAPCE pilots. The full integration of all services into the BUILDSPACE platform will guarantee seamless access for urban stakeholders and decision-makers.

With these final developments, the BUILDSPACE project will deliver a fully functional, integrated platform and suite of services, supporting European cities in their transition towards climate resilience and sustainable urban environments.

8. Conclusions

The **second technology release** of the BUILDSPACE Core Platform and services represents a significant milestone in the project, showcasing tangible advancements in both platform development and service functionalities.

One of the main goals of the BUILDSPACE WP3 is the creation of an interoperable platform that provides decision-support tools at both building and city scales, facilitating sustainable and resilient urban development in line with the Green Deal objectives. Significant advancements have been made in both backend and frontend development of the **Core Platform**, particularly in integrating Copernicus and GNSS Galileo services and developing a Python client for interfacing with the platform APIs.

For the building-scale services, the **Digital Twin Generation (SE1)** and **Digital Twin Enrichment (SE2)** services have progressed significantly, with enhanced automation, data accuracy and the integration of advanced machine learning and AI techniques. These developments allow for more comprehensive and precise monitoring of buildings during construction, renovation and operational phases. The use of UAVs and SLAM for detailed building data collection also enables the detection of critical issues in building envelopes, improving decision-making for construction and maintenance stakeholders.

At the city scale, the **Built Environment Climate Scenarios (SE3)** service has further developed its capacity to estimate the energy demand of the residential building stock under future climate scenarios. The development of the solar PV potential analysis provides additional value to stakeholders in making energy-related decisions. Similarly, the **Urban Heat Analysis and Resilience (SE4)** and the **Urban Flood Analysis and Resilience (SE5)** services have refined their methodologies to provide high-resolution assessment of urban heat vulnerability and flood risks. These services are increasingly tailored to local conditions, making them highly replicable across European cities while supporting local climate adaptation strategies.

The second technology release has been customised and validated in close collaboration with the pilots, ensuring that the services meet real-world needs and constraints. Moving forward, the focus will be on refining and completing the services in preparation for the third and final technology release. The next steps include further technical development, pilot validation and the integration of additional user feedback to ensure that the platform and services deliver maximum value to urban planners, building managers and policy-makers across Europe. It also involves the increase of the replicability of the services across Europe.

In conclusion, D3.2 marks a pivotal point in the BUILDSPACE project, as it demonstrates the practical capabilities of the Core Platform and services while laying the groundwork for the final release, ensuring that BUILDSPACE will effectively support Europe's urban sustainability and resilience goals.