

## URBREATH [101139711]

Systemic Integration of Transformative Technical and Nature-based Solutions to Improve Climate Neutrality of European Cities and Regions and tackle Climate Change: the URBreath Approach



### D4.2 Local Digital Twin and KPIs catalogue for urban NBSs – V2

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## Disclaimer

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## Executive Summary

Deliverable D4.2 focuses on the adaptation of the 3D model—which represents a Local Digital Twin (LDT) to every Frontrunner City (FRC). Its primary purpose is to report on the use of this LDT by Living Labs (LLs). This usage centers on comparing the simulated effects on urban areas before and after the adoption of Nature-Based Solution (NBS) measures. These scenarios are typically defined through participatory processes.

The deliverable is linked to Task 4.1 (T4.1). It details the technical foundation (tools and data) for the LDTs, reviews the maturity level of the LDTs in the URBREATH pilot cities (FRCs and FLCs), and the description and usage of the KPI catalogue.

The deliverable falls under Work Package 4 (WP4): URBREATH decision making framework. The core purpose is to report on the use of the Local Digital Twin 3D model by Living Labs (LLs). This usage involves comparing simulated effects on urban areas before and after the adoption of Nature-based Solution measures in scenarios defined through participatory processes.

The LDT framework uses the VC Map, a hybrid web-based mapping solution combining CesiumJS and OpenLayers. CesiumJS handles massive 3D datasets like 3D Tiles and excels at global WGS84 coordinates, while OpenLayers manages 2D/vector data and local Coordinate Reference Systems (CRS). Data consumption adheres to standards like 3D Tiles (for mesh models), WMS/WMTS (for raster overlays), and WFS (for feature access) and many more.

Key analysis tools and datasets created by URBREATH and integrated into the LDTs include:

- 3-30-300 rule/index which specifies measurable targets like seeing three trees, achieving 30% canopy cover, and living within 300 meters of accessible green space. This is integrated into the LDTs for Leuven, Madrid, Tallinn, and Cluj-Napoca.
- Urban Heat Islands Assessment (UHIs), which detects areas of high surface temperature using satellite-derived Land Surface Temperature (LST) data. This is available in the LDTs for Leuven, Madrid, Tallinn, and Cluj-Napoca.
- Walkability/15 min city index, which evaluates accessibility of essential services within a 15-minute walk or bike ride. This is integrated into the LDTs for Leuven, Aarhus, Parma, Athens, Cluj-Napoca, and Pilsen.
- Climate forecasts, based on CMIP6 simulations and Shared Socioeconomic Pathways (SSPs), focus on projected changes in mean annual temperature. These are available for Leuven, Madrid, Tallinn, and Cluj-Napoca.
- Shadow analysis, which simulates sunlight movement and calculates shadow coverage at user-defined intervals. The outcome of this tool relates to the KPI CR-KPI10 (Increase Shaded areas) for several pilots.
- Growing Trees plugin, which simulates the linear growth of urban trees, producing outputs like canopy coverage and CO<sub>2</sub> sequestration. This tool relates to KPI BIO-KPI7 (Increase share of NBS area covered by tree canopy).

- Small-scale BAF (Biotope Area Factor) calculation, which measures the proportion of ecologically effective surfaces. This tool relates to KPI BIO-KPI2.
- The VC Planner is the starting point for shadow analysis, growing trees, and BAF calculation tools.

The document also details the implementation and data inventory for several cities:

- The *Madrid* LDT uses 29 Cloud Optimized GeoTIFF (COG) layers focusing heavily on raster data for climate and heat vulnerability, including heatwave potential risk (2021–2023).
- The *Leuven* LDT integrates GeoJSON layers for water infiltration modeling (spring, summer, winter) alongside Urban Heat Island COG raster layers.
- The *Tallinn* LDT features numerous WMS layers for comprehensive noise mapping (street traffic, railways, industry, flight paths) categorized by time periods (day, evening, night).
- The *Cluj-Napoca* LDT features an extensive collection of VectorTile layers covering mobility, infrastructure, environmental data (forest cover, flood risk), and integrates air quality sensor data.
- The *Aarhus* LDT relies heavily on WMS layers for groundwater data, drilling, water supply, and quality assurance, complemented by the walkability VectorTile layer.
- The *Kajaani* LDT emphasizes winter urban management, including VectorTile and GeoJSON layers for potential snowpile deposits and the road network.
- The *Pilsen* LDT combines GeoJSON layers for greenery and air quality measurements with WMS layers for critical utilities like wastewater, fresh water, and power supply.

The deliverable utilizes the DUET Digital Twin Maturity Model to assess and estimate the maturity level of the LDTs, with phases including Awareness, Experimental, Predictive, and Intelligent Twins. The estimated current state according to the Maturity Model is provided for every pilot city.

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## List of Terms and Abbreviations

Table 1: List of Terms and Abbreviations

Abbreviation	Definition
3D Tiles	OGC - community standard designed for streaming and rendering massive 3D geospatial content.
BAF	Biotope Area Factor
COG	<b>Cloud Optimized GeoTIFF</b> : a GeoTIFF file with a specific internal structure that allows for efficient access to data over the internet, making it ideal for cloud-based workflows.
FlatGeobuf	A performant binary encoding for geographic data based on flatbuffers that can hold a collection of Simple Features including circular interpolations as defined by SQL-MM Part 3.
FLC	Follower City
FRC	Frontrunner City
FROST server	A Server implementation of the OGC SensorThings API. The <b>FR</b> auhofer <b>O</b> pensource <b>S</b> ensor <b>T</b> hings-Server is a complete, open-source official reference implementation of the OGC SensorThings API Part 1: Sensing 1.0. It also implements OGC SensorThings API Part 1: Sensing 1.1 and OGC SensorThings API Part 2: Tasking Core 1.1.
GeoNetwork	<b>GeoNetwork</b> is a catalog application to share information for search and discovery. Contents are managed with a full set metadata editing and review tools backed by a publication workflow.
IDRA	<b>Idra</b> is a web application able to federate existing Open Data Management Systems (ODMS) based on different technologies providing a unique access point to search and discover open datasets coming from heterogeneous sources.
KPI	Key Performance Indicator
LDT	Local Digital Twin
LLL	Local Living Lab
LST	Land Surface Temperature
LOD <sub>1</sub>	A simplified 3D model of buildings with extruded block shapes, typically based on the building footprint and average height. It provides a basic representation of urban structures without detailed architectural features.
LOD <sub>2</sub>	An enhanced 3D model of buildings with additional geometric details, such as roof structures and more accurate heights. It provides better visualization for urban analysis and planning.
LOD <sub>3</sub>	A highly detailed 3D model of buildings, that includes architectural elements like windows, doors, and façade details. It is used for advanced applications such as simulations and realistic visualizations.

NBS	Nature-based Solution
OGC	Open Geospatial Consortium is an international organization dedicated to developing open standards for geospatial and location-based services.
OpenAQ	OpenAQ is a nonprofit organization providing universal access to air quality data to empower a global community of changemakers to solve air inequality—the unequal access to clean air.
OSM	Open Street Map
Piveau	<b>piveau</b> is a data management ecosystem for the public sector. It provides components and tools to support the entire data processing chain from harvesting, aggregation, provision, and use.
SensorThings API	The <b>OGC SensorThings API</b> is an OGC standard specification for providing an open and unified way to interconnect IoT devices, data, and applications over the Web. The SensorThings API is an open standard, builds on Web protocols and the OGC Sensor Web Enablement standards, and applies an easy-to-use REST-like style. The result is to provide a uniform way to expose the full potential of the Internet of Things.
Task	T
Telraam	<b>Telraam</b> is your citizen-powered solution for collecting multi-modal traffic data with a purpose-built, affordable, and user-friendly traffic counter.
TMS	OSGeo - Tiled Map Service Specification
UHI	Urban Heat Island
WFS	OGC - Web Feature Service: an internet-based service that provides access to geographic vector data, like roads or rivers, from a distributed Geographic Information System (GIS).
WMS	OGC - Web Map Service: standard providing a simple HTTP interface for requesting geo-registered map images.
WMTS	OGC - Web Map Tile Service: implementation standard providing a standard based solution to serve digital maps using predefined image tiles.
WP	Work Package

# 1 Introduction

This deliverable is an accompanying document to the LDT-Demonstrators of Task 4.1 in WP4 of URBREATH and is the second version, based on D4.1 - *Local Digital Twin and KPIs catalogue for urban NBSs - V1* (delivered in 12/2024, M12). This deliverable will focus on the adaptation of the 3D model to every FRC and report on its use by LLs while comparing the simulated effects on urban areas assessed before and after the adoption of NBS measures in scenarios defined through participatory processes. This deliverable is linked to T4.1.

## 2 Foundation

In this chapter, the foundation (tools and data) valid for all LDTs (FRCs and FLCs) will be highlighted. In the chapters followed by this, specific tools or datasets will be described relevant to specific LDTs.

### 2.1 LDT datasets

A **Local Digital Twin (LDT)** of a city is a visually rich, interactive 3D environment that merges diverse urban datasets into a unified geospatial experience. Within such a framework, data visualization is driven by the city's digital geometry—buildings, terrain, and infrastructure—while dynamic data layers, sensors, and simulations are rendered as responsive overlays that animate the living pulse of the city. The implementation of each Local Digital Twin (LDT) in URBREATH relies on VC Map, a hybrid web-based mapping solution combining **CesiumJS** and **OpenLayers** to address the disparate requirements of 3D global visualization and 2D local GIS precision. Thus, a robust, standard-compliant framework for the ingestion, processing, and rendering of heterogeneous urban datasets, is given.

This hybrid approach enables capabilities essential for a comprehensive LDT:

- **2D/3D Synchronization & Switching:** The key capability is the seamless, on-demand switch between a high-precision 2D map view (handled by OpenLayers, ideal for local projections and standard GIS operations) and a global 3D globe view (powered by CesiumJS, ideal for visual context and large-scale data). Map position, zoom, and visible layers are synchronized bidirectionally.
- **Data Handling:**
  - **CesiumJS:** Handles massive 3D datasets like 3D Tiles (for streamed building models, photogrammetry, point clouds) and glTF (for detailed individual models) with optimal performance. It excels at global WGS84 coordinates.
  - **OpenLayers:** Excels at handling standards-based 2D/vector data and local Coordinate Reference Systems (CRS), which are critical for accurate cadastral, planning, and engineering applications. It provides robust tools for vector editing and complex on-the-fly reprojection.
- **Rich Standards Support:** The combined platform ensures comprehensive interoperability:

- *2D GIS Standards (OpenLayers)*: Native, robust support for WMS (Web Map Service) and WMTS (Web Map Tile Service) for base maps and raster overlays, and WFS (Web Feature Service) for accessing and potentially editing vector features (via conversion to internal formats like GeoJSON).
- *3D Geospatial Standards (CesiumJS)*: Native support for high-performance streaming formats like 3D Tiles and CZML (Cesium's JSON for dynamic, time-based data), which are fundamental for LDT visualization.

At the *foundation* of each LDT lies geospatial and infrastructure data, represented as 3D Tiles, CityGML, or BIM-derived models (IFC, glTF). These form the digital canvas: realistic building blocks (textured with materials), heights, and attributes. Roads, parks, and underground networks can be visualized as extruded geometries or vector tiles that respond to user interactions, such as highlighting zoning boundaries or showing utility corridors beneath the surface.

Above these structural layers, a lot of geospatial data brings the city to life, such as environmental data, air quality, temperature, or noise level data. These datasets are sourced and integrated through the robust data ingestion and processing framework outlined earlier, ensuring that both real-time and historical information are accurately represented within the Local Digital Twin (LDT). Data can be retrieved from a variety of open data portals spanning multiple scales—European-wide sources like <https://data.europa.eu>, national portals such as [https://data.gov.ro/dataset/calitate\\_aer](https://data.gov.ro/dataset/calitate_aer), or city-specific repositories like <https://www.opendata.dk/city-of-aarhus>. Typically, these datasets originate from national institutions dedicated to environmental monitoring or urban management, as well as from individual cities that collect, analyze, and publish their own data using domain-specific tools and analytical platforms. Such institutions and municipal agencies often leverage specialized software for air quality monitoring, meteorological analysis, or urban noise mapping, producing standardized datasets that are made accessible for integration into digital twin platforms.

Energy and utilities data can be layered as interactive dashboards embedded within the 3D scene. Power consumption, solar generation, or water flow can be expressed as dynamic markers or graphs linked to buildings or substations. These datasets may also be sourced from national energy authorities, municipal utility companies, or open infrastructure data platforms, each providing granular, often real-time data streams that enrich the digital twin's visualization capabilities.

Socioeconomic and demographic information integrates seamlessly as thematic maps, and, when available as vector features, can also be extruded into the third dimension. Population density, income levels, or accessibility indexes can rise from the urban fabric as vertical prisms, using color gradients and elevation to convey disparities or growth trends. These data layers are often drawn from census bureaus, statistical offices, or targeted urban studies, with data aggregated at various administrative levels and published through open government portals or city analytics dashboards. The integration and visualization of these datasets rely on the technological foundation described above, leveraging tools and standards detailed in Chapter 2.2 ("LDT Tools"). The precise data sources and formats for these layers are further explained in the following sections and are subject to data availability in each city or region.

When combined with zoning or land-use data, frequently published by planning departments or national land registries, layers enable intuitive exploration of spatial equity and policy outcomes, supporting evidence-based decision making and fostering transparency in urban governance.

Building Information Modeling (BIM) elements add another layer of depth. Detailed 3D building models—converted from Revit or IFC—can reveal internal structures, materials, or occupancy data when selected. Cesium’s glTF support allows smooth transitions between exterior city views and interior asset visualizations, creating a bridge between macro-urban scale and micro-asset management.

Predictive and simulation data expands the twin into the future. Urban growth projections, traffic forecasts, or climate scenarios can be visualized as evolving morphologies, where new developments fade in our climate zones shift over time. This allows users to scrub through scenarios, comparing present and potential futures within the same 3D viewport.

Administrative and policy data, such as zoning regulations, land ownership, or planning boundaries, can be rendered as transparent overlays that can be toggled on and off. They enable decision-makers to visually intersect policy layers with environmental or demographic data, making spatial governance more intuitive.

Finally, citizen and participatory data can appear as geolocated feedback points, social media heatmaps, or dynamic markers representing community interactions. These elements humanize the digital twin, showing not just infrastructure and data streams, but the lived experience of the urban population.

### **Standardized Data Ingestion and Rendering Pipeline**

The framework's capability is defined by its adherence to OGC and web-native standards for data consumption:

**Table 2: Standardized Data Ingestion and Rendering Pipeline**

Data Type	Primary Standard	Engine Consumption Mechanism	Technical Rationale
<b>3D Mesh Models</b>	3D Tiles (OGC Community Standard)	CesiumJS (via Cesium3DTileset)	Optimized for massive, heterogeneous datasets (BIM, photogrammetry, CityGML). Utilizes Hierarchical Level of Detail (HLOD) and spatial indexing for efficient streaming and frustum culling.
<b>Elevation Data</b>	Quantized Mesh (or GeoTIFF/WMS)	CesiumJS (via CesiumTerrainProvider)	Provides global, high-resolution terrain geometry, enabling accurate line-of-sight and shadow analysis relative to the terrain surface.
<b>Raster Overlays</b>	WMS / WMTS (OGC Standards)	OpenLayers (via TileLayer) and CesiumJS (via ImageryProvider)	Provides georeferenced base maps and thematic raster data. OpenLayers handles local projection re-sampling; CesiumJS textures the globe.
<b>Static Vector Data</b>	GeoJSON (IETF Standard)	OpenLayers (via VectorSource) & CesiumJS (via DataSource)	Acts as a versatile interchange format. OpenLayers processes feature geometry and attributes for 2D display; CesiumJS converts to primitives or uses Entity API for 3D visualization (e.g., polygon extrusion).
<b>Dynamic/Real-Time Data</b>	CZML (Cesium's JSON Format)	CesiumJS (via CzmlDataSource)	Specialized for visualizing time-dynamic, animated data (trajectories, sensor readings, object movement) using the JulianDate time standard.
<b>Feature Access</b>	WFS (OGC Standard)	OpenLayers (via VectorSource with WFS parser)	OpenLayers is typically used to interface with a WFS endpoint for attribute querying and small-scale feature retrieval, where its internal feature management is leveraged.

## 2.1.1 Datasets created by URBREATH tools

### 2.1.1.1 3-30-300 rule / index

As explained and described in D4.1 - Local Digital Twin and KPIs catalogue for urban NBSs - V1 D4.7 , the 3-30-300 Rule is a strategic guideline in urban planning aimed at improving the livability, health, and environmental resilience of cities through increased access to trees and green spaces. This rule provides measurable targets that municipalities and planners can use to assess and enhance urban nature integration.

Key Principles:

1. Visibility of Trees—"3 Trees"

Every resident should be able to see at least three trees from their home. This principle emphasizes the importance of visual contact with nature, which has been linked to improved mental health, reduced stress levels, and enhanced overall well-being.

2. Tree Canopy Coverage – "30% Canopy"

Urban neighborhoods should aim to achieve a minimum of 30% tree canopy cover. A well-developed canopy contributes to:

- Mitigating urban heat island effects by providing shade and cooling,
- Improving air quality through pollutant filtration,
- Supporting biodiversity by creating habitats for various species.

3. Proximity to Green Spaces – "300 Meters"

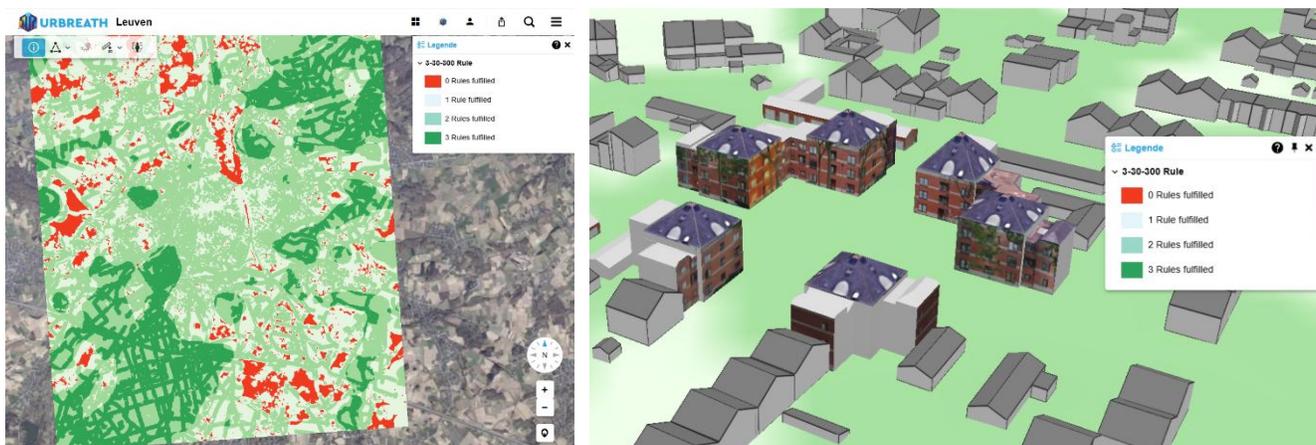
All residents should live within 300 meters of a publicly accessible green space, such as a park, garden, or natural area. Close proximity encourages regular use, promoting physical activity, social interaction, and mental restoration.

Link to Leuven LDT [here](#).

Table 3: 3-30-300 availability (according to city interest)

Pilot	Dataset available	Dataset integrated in LDT
Leuven	yes	yes
Aarhus	no	no
Madrid	yes	yes
Parma	no	no
Athens	no	no
Tallinn	yes	yes
Kajaani	no	no
Cluj-Napoca	yes	yes
Plzen	no	no

Figure 1: 3-30-300 rule integrated into the LDT of Leuven (City wide context *left*; NBS area context *right*)



### 2.1.1.2 Urban heat islands

As described in D4.1 - Local Digital Twin and KPIs catalogue for urban NBSs - V1

D4.7 Urban Heat Island Assessment - provides a data-driven approach to identifying and analyzing Urban Heat Islands (UHIs) using satellite-derived Land Surface Temperature (LST) data. It is designed to support urban planners, environmental analysts, and policy makers in understanding temperature variations within urban environments.

#### Objective

To detect and quantify areas within cities that exhibit significantly higher surface temperatures compared to surrounding rural zones. These temperature anomalies are primarily caused by factors such as:

- Dense infrastructure and built surfaces,
- Limited vegetation cover,
- Intensified human activity and urbanization.

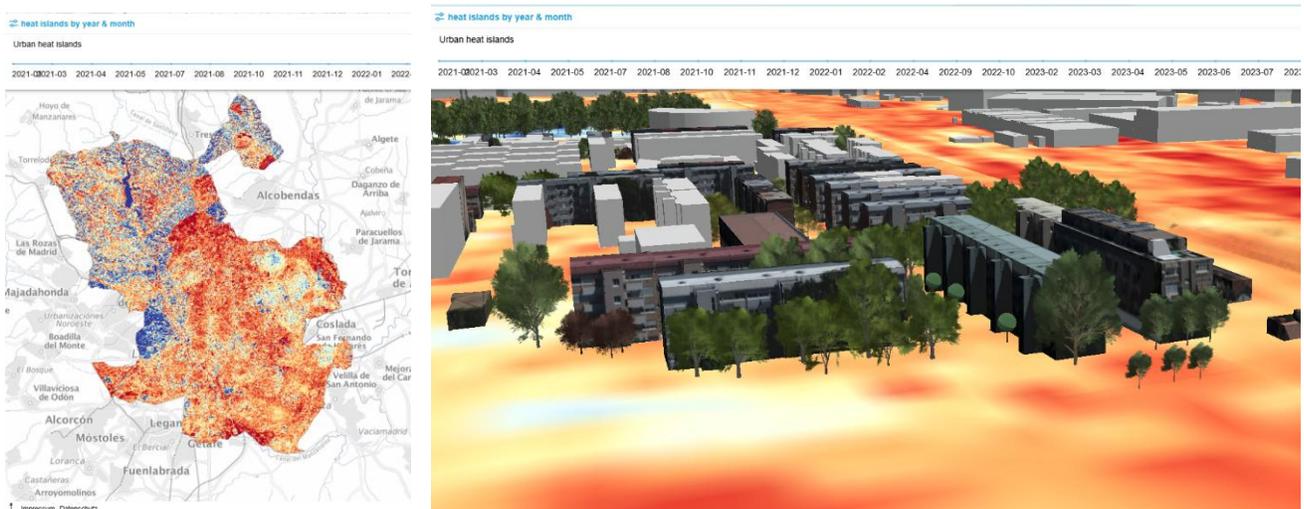
### Methodology

The module processes satellite LST data to generate a UHI Intensity Index, expressed as a percentage scale ranging from 0 to 100. This index reflects the relative severity of heat concentration in specific urban zones, enabling targeted analysis and comparison across regions.

Since the datasets produced relate to selected month and year, the datasets can be visualized in conjunction with a time slider, so that it is easy for the user to select another time period and the respective dataset will be shown.

Link to Madrid LDT [here](#).

**Figure 2: Urban Heat Islands dataset integrated into the LDT of Madrid (Villaverde). Left – City wide context; Right – NBS intervention context**



**Table 4: Urban Heat Islands datasets availability (according to city interest)**

Pilot	Dataset available	Dataset integrated in LDT
Leuven	yes	yes
Aarhus	no	no
Madrid	yes	yes
Parma	no	no
Athens	no	no
Tallinn	yes	yes
Kajaani	no	no
Cluj-Napoca	yes	yes
Plzen	no	no

#### 2.1.1.2.1 KPI relation

The outcome of the tool relates to D5.1 – Annex V, page 112, CR-KPI9 (Decrease Urban Heat Island (UHI) Effect) is relevant to Pilots:

Leuven (FRC), Cluj-Napoca (FRC), Madrid (FRC), Parma (FLC) and Pilsen (FLC).

#### 2.1.1.3 Walkability / 15 min city index

This algorithm is developed to evaluate the accessibility of essential services within a defined urban territory. It assigns a Proximity Index to various points of interest (POIs), measuring how easily they can be reached on foot or by bicycle. The methodology aligns with the principles of the “15-minute city” concept, introduced by urbanist Carlos Moreno<sup>1</sup>, which envisions that most daily needs should be accessible within a 15-minute walk or bike ride from one’s residence.

#### Purpose

The core objective is to provide a quantitative measure of service accessibility, enabling cities to assess how well their infrastructure supports local living. This supports planning efforts aimed at reducing car dependency, enhancing walkability, and promoting sustainable mobility.

#### Key Features

Globally applicable, locally detailed: The algorithm is designed to be adaptable across different geographic contexts while maintaining high spatial resolution. To ensure broad usability and replicability, the algorithm relies exclusively on freely available, open-source datasets, making it accessible to municipalities, researchers, and planners worldwide.

#### Result

The result of the 15-Minute City Index is presented as a spatial analysis using a hexagonal grid, where each hexagon represents a 250-meter area. Each hexagon is evaluated based on walking or cycling time to the nearest essential services—such as groceries, healthcare, education, parks, and others—using pedestrian-accessible routes only.

Based on this analysis, each hexagon is classified into one of five categories:

- 15-minute zone: All essential services are reachable within 15 minutes.
- 30-minute zone: At least one service requires between 15 and 30 minutes to reach.
- 60-minute zone: At least one service requires between 30 and 60 minutes.
- Low-proximity zone: At least one service is not reachable within 60 minutes.
- No-proximity zone: None of the essential services are reachable within 60 minutes.

The LDT viewer provides live styling according to each of the 8 classes, giving the pilots cities to inspect the walkability in general and in detail for each of the classes. This classification provides a clear,

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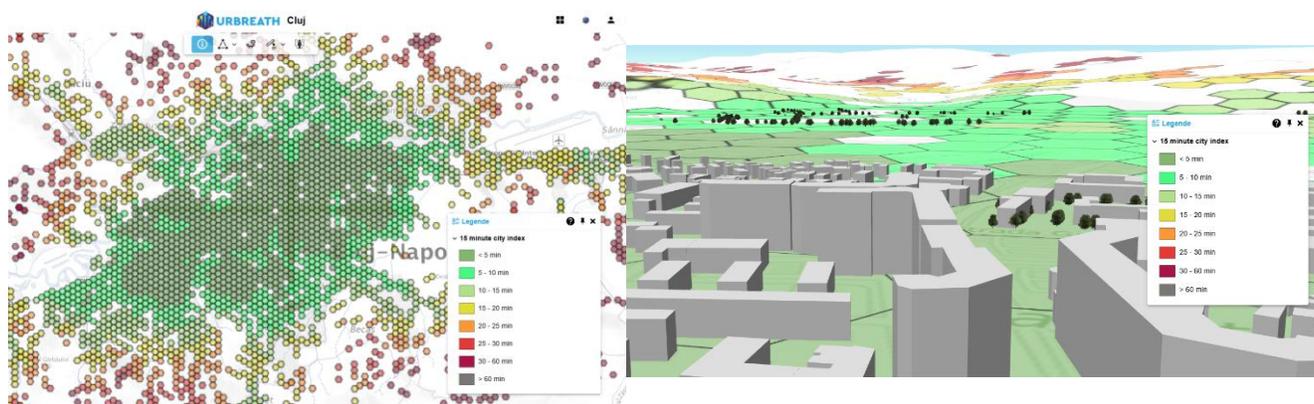
<sup>1</sup> <https://www.mdpi.com/2624-6511/4/1/6>

location-specific overview of service accessibility, supporting urban planning decisions aimed at improving local livability and reducing travel dependency.

**Table 5: 15 min city index availability (according to city interest)**

Pilot	Dataset available	Dataset integrated in LDT
Leuven	yes	yes
Aarhus	yes	yes
Madrid	no	no
Parma	yes	yes
Athens	yes	yes
Tallinn	no	no
Kajaani	no	no
Cluj-Napoca	yes	yes
Pilsen	yes	yes

**Figure 3: 15 min city index dataset integrated into the LDT of Cluj-Napoca. Left – City wide context; Right – NBS intervention context**



#### 2.1.1.4 Climate projections

Climate forecasts are essential tools for understanding how key environmental variables—such as temperature, precipitation, and extreme weather events—may evolve under different socio-economic and emission scenarios. These forecasts are generated using advanced climate models that simulate the Earth's climate system based on physical principles and observed data.

Here, projections are based on simulations from the **Coupled Model Intercomparison Project Phase 6 (CMIP6)**, see <https://wcrp-cmip.org/cmip-phases/cmip6/> for further information), which provides a standardized framework for comparing climate model outputs across a range of future scenarios. These scenarios, known as **Shared Socioeconomic Pathways (SSPs)**, combine assumptions about global

development trends (e.g., population growth, energy use, land use) with varying levels of greenhouse gas emissions and radiative forcing by the year 2100.

The purpose of these forecasts is not to predict a single outcome, but to explore a range of plausible futures. This helps policymakers, planners, and researchers assess risks, identify adaptation needs, and develop strategies for mitigation. The projections presented here focus on changes in mean annual temperature, a key indicator of climate change, and are analyzed across three time periods: the historical reference period (1985–2014), mid-century (2036–2065), and end-of-century (2071–2100).

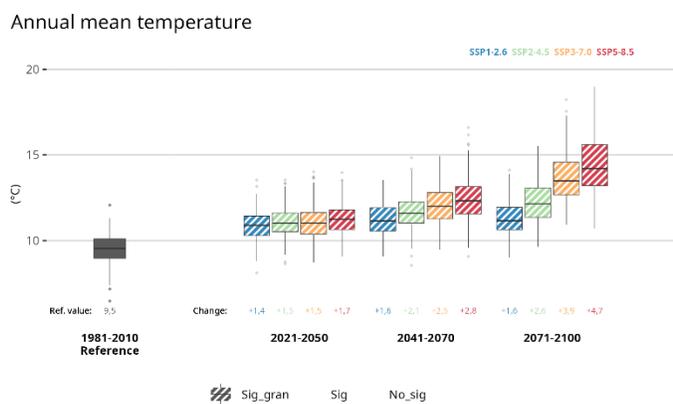
### Temporal Evolution of Simulated Variables and Results

The projected changes in the analyzed variables over the 21st century are illustrated using box-and-whisker plots, which provide a statistical summary of their distribution relative to a defined reference period (1985–2014). These plots are organized along the X-axis into three distinct timeframes:

- Reference period (1985–2014)
- Mid-century (2036–2065)
- End-of-century (2071–2100)

The Y-axis represents the values of the simulated variable—here, the mean annual temperature. Each box-and-whisker plot conveys key statistical information:

**Figure 4: Example result of Climate projection**



The central line within each box marks the median (50th percentile), indicating the midpoint of the distribution. The box edges represent the first (25th percentile) and third quartiles (75th percentile), capturing the interquartile range where 50% of the values lie. The whiskers extend to the limits for detecting outliers, which are shown as individual points beyond the whiskers.

For the reference period, a single grey box plot is shown, based on historical simulations from CMIP6 climate models. For mid- and end-century projections, four box plots are displayed per period, each corresponding to a different emission scenario. These scenarios combine socio-economic pathways (SSPs) with radiative forcing levels expected by 2100:

- SSP1-2.6 (blue) – most optimistic
- SSP2-4.5 (green)
- SSP3-7.0 (yellow)
- SSP5-8.5 (red) – most pessimistic

The box plots also incorporate patterning to indicate the statistical significance and magnitude of change compared to the reference period:

- No pattern: non-significant or small-scale changes
- Low-density diagonal lines: moderate-scale significant changes
- High-density diagonal lines: large-scale significant changes (currently observed for all future scenarios)

Statistical significance is assessed using the Wilcoxon Mann-Whitney test<sup>2</sup>, and the magnitude of change is evaluated via the Wilcoxon effect size.

Finally, the expected change in median temperature for each scenario and future period is quantified numerically. These values, calculated as the difference between the future and reference medians, are displayed below each corresponding box plot.

### Results

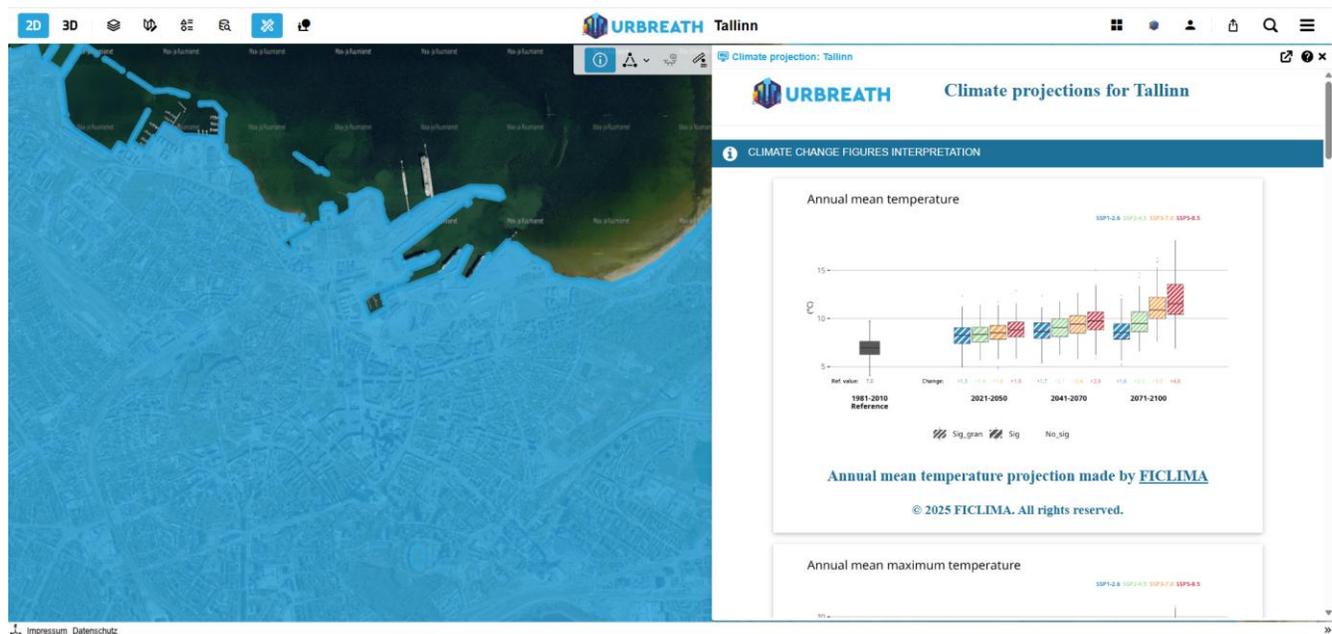
The results are arranged in an own webpage showing the boxplots foreach simulated variable and Shared Socioeconomic Pathways (SSPs) and in the LDT

**Table 6: Climate projection availability**

Pilot	Dataset available	Dataset integrated in LDT	URL
Leuven	yes	yes	<a href="https://urbreath.virtualcitymap.de/climate/leuven/">https://urbreath.virtualcitymap.de/climate/leuven/</a>
Aarhus	no	no	
Madrid	yes	yes	<a href="https://urbreath.virtualcitymap.de/climate/madrid/">https://urbreath.virtualcitymap.de/climate/madrid/</a>
Parma	no	no	
Athens	no	no	
Tallinn	yes	yes	<a href="https://urbreath.virtualcitymap.de/climate/tallinn/">https://urbreath.virtualcitymap.de/climate/tallinn/</a>
Kajaani	no	no	
Cluj-Napoca	yes	yes	<a href="https://urbreath.virtualcitymap.de/climate/cluj/">https://urbreath.virtualcitymap.de/climate/cluj/</a>
Pilsen	no	no	

<sup>2</sup> [https://en.wikipedia.org/wiki/Mann%E2%80%93U\\_test](https://en.wikipedia.org/wiki/Mann%E2%80%93U_test)

Figure 5: LDT of Tallinn, showing the integrated Climate projection on the right-hand side



### 2.1.2 City-owned datasets

City-owned datasets play a pivotal role in shaping urban planning, environmental monitoring, and public service delivery. Across various European cities, a wide array of datasets is being made available, reflecting both the diversity of urban challenges and the technological maturity of municipal data infrastructures. These datasets span themes such as land use, air quality, traffic, vegetation, noise pollution, and climate, and are often structured to support specific analytical frameworks like the “3-30-300” rule or the 15-minute city index.

A key aspect of these datasets is their format, which determines accessibility, interoperability, and analytical potential. Common geospatial formats such as *GeoTIFF*, *GeoJSON*, *Shapefiles*, and *OGC WMS/WFS* services are widely used, enabling integration into GIS platforms and urban simulation tools. For sensor-based and time-series data, formats like *CSV*, *SensorThings API (JSON/GeoJSON)*, and *Overpass API* are prevalent, supporting real-time monitoring and longitudinal studies. Some cities also provide data in more specialized formats like *CityGML*, *Geopackage*, or *ESRI Multipatch*, particularly for 3D building models and terrain analysis.

While some datasets are marked as “good to go,” indicating readiness for use, others are flagged for improvement or require validation, especially when sourced from fallback providers or external platforms like OpenStreetMap or Copernicus. This highlights the ongoing need for cities to not only publish data but also ensure its quality, completeness, and relevance to local contexts. The presence of

fallback datasets ensures continuity in analysis when city-specific data is unavailable, but the future goal remains the provision of high-resolution, locally curated datasets.

In summary, the landscape of city-owned datasets is rich and evolving, with formats playing a central role in enabling data-driven urban transformation. The harmonization of formats and the commitment to data quality are essential steps toward smarter, more resilient cities.

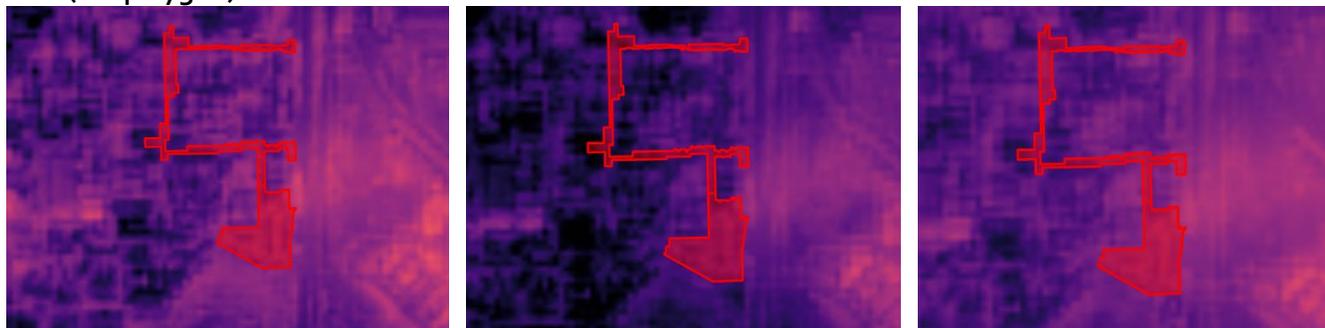
Some datasets are relevant to perform analysis like 3-30-300, urban heat islands and walkability while others are dedicated to being displayed / integrated into the viewer directly.

Integrating city-owned datasets into the LDT viewer serves several strategic and operational purposes. At its core, the intention is to make complex urban data accessible, interpretable, and actionable for a wide range of stakeholders, from city planners and researchers to citizens and policymakers. By visualizing datasets such as building footprints, vegetation cover, air quality measurements, traffic flows, and climate indicators, the viewer becomes a central interface for understanding spatial patterns, identifying challenges, and supporting evidence-based decision-making.

The viewer acts as a bridge between raw data and meaningful insights. It allows users to explore datasets in their native formats, whether GeoTIFFs for elevation models, GeoJSONs for spatial features, or APIs for real-time sensor data—without needing specialized software or technical expertise. This democratization of data fosters transparency and encourages civic engagement, enabling communities to better understand their environment and participate in urban development processes.

Moreover, the integration of multiple datasets into a single platform supports cross-domain analysis. For example, combining noise pollution layers with traffic data and green space distribution can reveal correlations that inform health impact assessments or urban greening strategies. The viewer also facilitates monitoring over time, especially when time-series data are available. While formats like CSV or SensorThings API are used in dashboards, analysis data displayed over time helps cities track progress toward sustainability goals or respond to emerging issues.

**Figure 6: Heat wave risk in Madrid-Villaverde from left to right (2021,2022,2023) with NBS intervention area (red polygon)**



## 2.2 LDT tools

In addition to the traditional tools such as the Information tool, Drawing tool, Camera Flights, and Measurement tool (as shown in left Figure from left to right), the LDT Viewer within the Virtual City Map platform offers a suite of advanced analysis tools that significantly enhance spatial understanding and planning capabilities, see figure left (from left to right). These include the Swipe Content tool, which enables users to visually compare different data layers or scenarios by sliding across the screen, making it ideal for change detection or planning comparisons. The Ground Excavation tool allows for the simulation of terrain removal, supporting construction planning and underground infrastructure analysis. Viewshed Analysis calculates the visible areas from a specific vantage point, which is particularly useful for evaluating surveillance coverage, scenic viewpoints, or advertising visibility. The Line-of-Sight tool determines whether two points in the model have a direct visual connection, aiding in telecommunications planning or architectural design. Lastly, the Height Profile Analysis generates elevation profiles along a selected path, providing valuable insights for infrastructure development, accessibility studies, and terrain evaluation. These advanced tools collectively empower users to perform detailed spatial analyses directly within the 3D city model environment.

Figure 7: Result of a viewshed analysis in Madrid Villaverde, analyzing a view from roof top towards the district (left the viewshed cone with orange highlighted visibility items and right the viewer perspective)

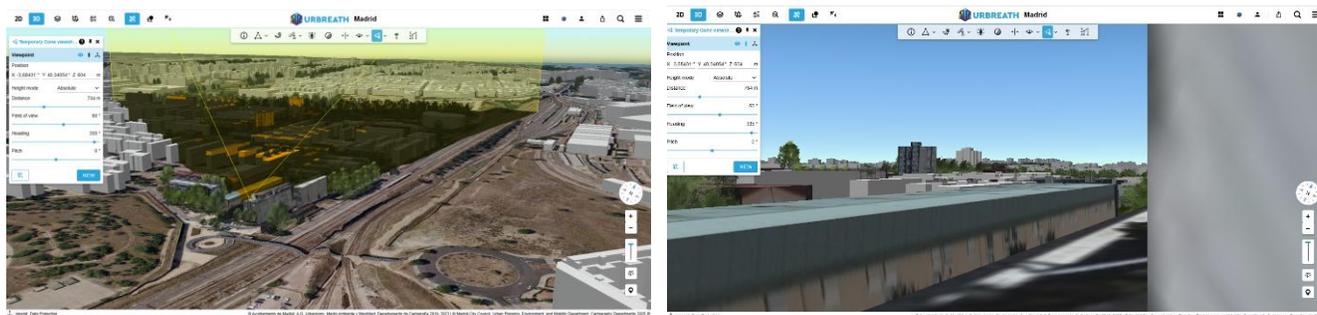


Figure 8: Result of a Line-of-Sight analysis, analyzing if a specific object is visible from a certain position in LDT (as it turns out, a tree blocks the visibility of the northern object from roof top position)

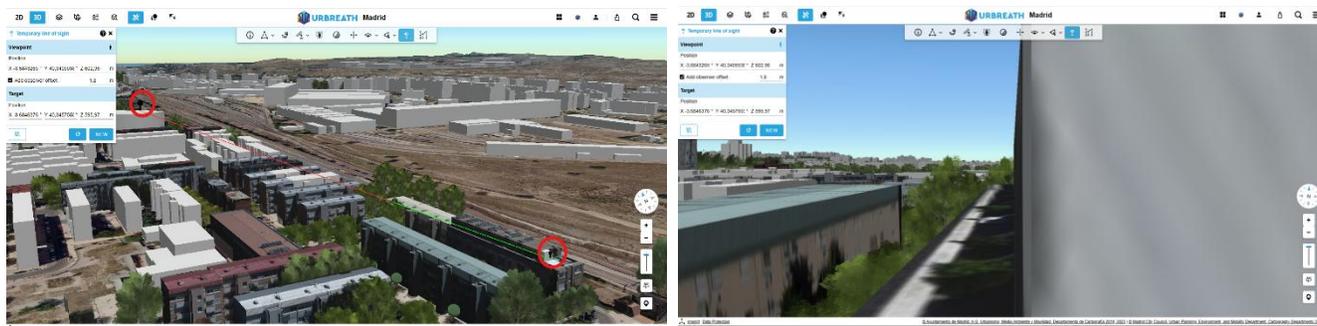


Figure 9. Underground analysis performed in Leuven’s LDT, inspecting the below-ground infrastructure



All tools mentioned above are available across all nine Local Digital Twins (LDTs), ensuring that each pilot has access to the full range of analysis capabilities described. This consistent toolset empowers users to perform advanced spatial analyses regardless of the specific datasets available in each pilot. While certain analyses—such as ground infrastructure evaluation—may depend on the presence of particular data layers, the platform itself provides the necessary functionality to support these tasks wherever the data is present.

In addition to the tools previously described, the LDT Viewer also includes a set of advanced functionalities specifically designed to support Nature-Based Solutions (NBS) planning and the URBREATH initiative. These specialized tools play a crucial role in enabling targeted environmental and urban resilience analyses. They will be introduced and discussed in more detail in the following subchapters, highlighting their relevance and application within the broader context of sustainable urban development.

## 2.2.1 Dynamic layer

The Dynamic Layer Tool in VC Map allows users to flexibly add and manage external geospatial data layers without requiring prior configuration. It supports a wide range of data formats and services, including OGC standards like WMS, WMTS, WFS, as well as 3D Tiles, point clouds, terrain data, GeoJSON, and CZML.

The tool is structured into three main tabs:

**Web Data Tab:** Enables users to connect to external web services by entering service URLs. Once connected, users can browse available layers, view metadata, and add selected layers directly to the map. Layers added in this way are included in shareable map links and can be edited or removed during the session.

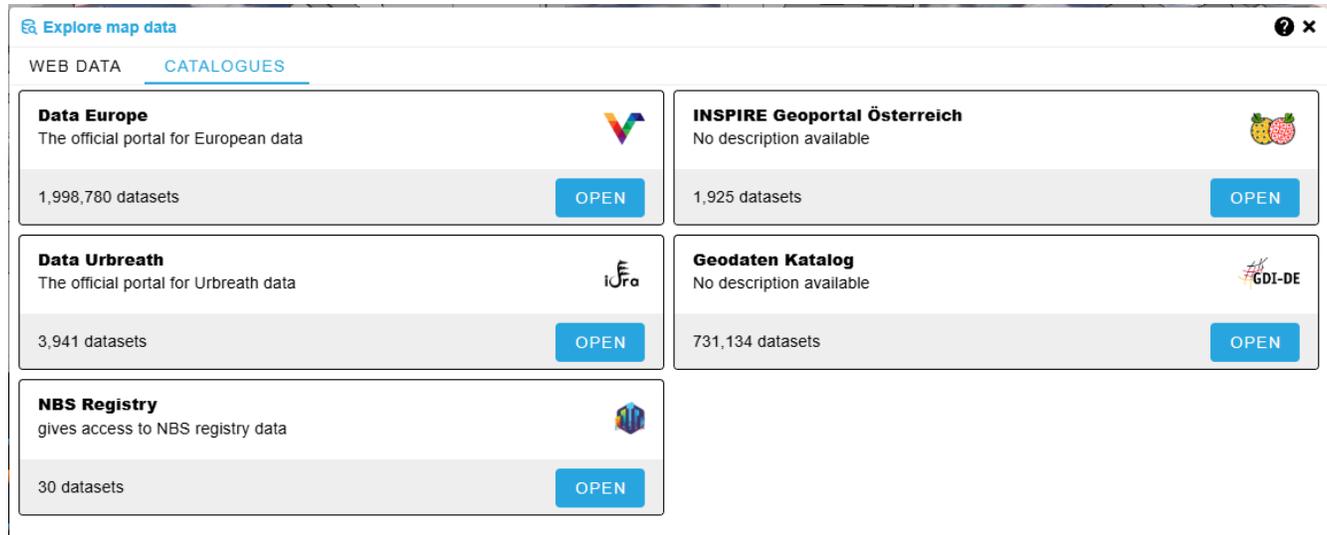
**Catalogues Tab:** Provides access to preconfigured data catalogues (e.g., Piveau, GeoNetwork, Idra). For URBREATH use, the tool also supports the NBS registry (see D4.1 - Local Digital Twin and KPIs catalogue for urban NBSs - V1

D4.7 chapter 4.7.1). Users can search, filter, and explore datasets, and add compatible distributions (e.g., WMS, GeoJSON) to the map. Metadata standards like ISO 19115, DCAT, and INSPIRE are supported, see **Errore. L'origine riferimento non è stata trovata..**

**Added Data Tab:** Lists all layers added via the plugin, grouped by type. Users can view metadata, adjust parameters (e.g., opacity, style, zoom levels), and remove layers. Custom settings apply only to the current session.

The Dynamic Layer Tool is designed to support flexible exploration and integration of spatial data, significantly enhancing the analytical capabilities and adaptability of VC Map for planners, analysts, and decision-makers. With this tool, pilots can incorporate external datasets that are not statically integrated into the viewer. This allows for dynamic enrichment of the map environment, enabling more tailored and context-specific analysis even in cases where certain data layers, such as those required for ground infrastructure assessments, may not be available by default.

Figure 10. available catalogues in Dynamic Layer plugin of LDT viewer, at least the *Data Europe*, *Data Urbreath* and *NBS Registry* are relevant for pilots



## 2.2.2 Telraam sensor readings

The Telraam plugin integrates traffic segment data into the LDT viewer application and provides an interactive workflow for users to discover, visualize, and inspect measurements from the Telraam network. When initialized, it registers a custom declarative style (Telraam) that color-codes road segments by car counts per hour using a graduated legend (from light yellow for 0/h through deep purple and black for heavy volumes  $\geq 2000/h$ ). This style of logic is implemented with ordered numeric conditions applied to each feature’s car property, ensuring intuitive visual density mapping. The plugin also fixes a consistent stroke width to make segments visually prominent.

It adds a feature info view (TelraamFeatureInfoView) marked volatile, so it does not persist unintentionally across sessions. When users interact with segments, the view presents localized (English/German) labels, current and historical measurement metadata (cars, bikes, heavy vehicles, pedestrians, speed), period, timezone, and a link tooltip for external refinement. The plugin supplies internationalized UI strings for layer addition, drawing tools (bounding box or polygon selection), workflow step titles, validation messages, and feedback after successful layer insertion.

Beyond visualization, a key capability is the FeatureInfo view (TelraamFeatureInfoView), which provides dynamic, context-aware inspection of segment measurements. When a user selects or hovers a segment (depending on app interaction patterns), the view retrieves the latest available observations for multiple traffic modes—cars, bikes, heavy vehicles, pedestrians—as well as speed (v85) and temporal metadata (date, period, timezone). It supports configurable temporal scope via the number of past days (requestDays), enabling quick longitudinal comparison without manual reload complexity.

The view is registered as volatile, meaning it won't persist unintentionally between sessions, aligning with transient analytic workflows.

The FeatureInfo (see **Errore. L'origine riferimento non è stata trovata.**) panel also:

- Surfaces a link tooltip for deep dives into the originating Telraam segment.
- Differentiates between successful and unsuccessful data retrieval, presenting user-friendly warning messaging when no measurements are returned.
- Separates current snapshot values from the selectable historical range (“last x days”), making temporal context explicit.
- Provides structured grouping of observational properties so stakeholders can rapidly scan modal distributions (e.g., balancing pedestrian vs. vehicular flow).

The underlying configuration model is lightweight: defaults (API proxy URL, chart type, time span, and future-facing flags for noise and traffic prediction) are merged with user-supplied options, and serialization emits only deviations—keeping exported or persisted config minimal and auditable. A toggle action installs a dedicated Telraam window into the dynamic UI region, guiding users through adding data layers and optionally drawing spatial selection geometries (bounding box or polygon) to scope requests.

Taken together, the plugin delivers: high-fidelity thematic rendering; a dynamic, multilingual FeatureInfo analytics surface; modular configuration prepared for predictive extensions (noise/traffic flags); and clean lifecycle management for initialization and teardown. It transforms static map exploration into an interactive traffic intelligence experience with real-time contextual measurement access.

**Figure 11. Telraam sensor readings and road segments in Leuven's LDT**

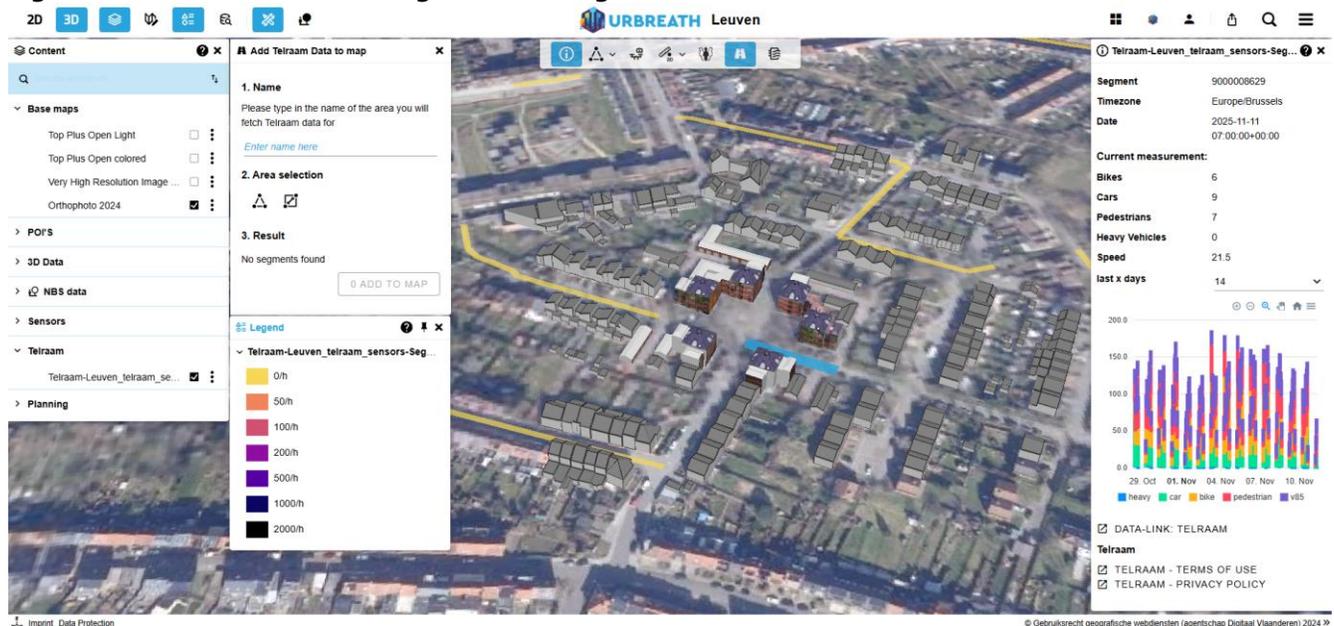
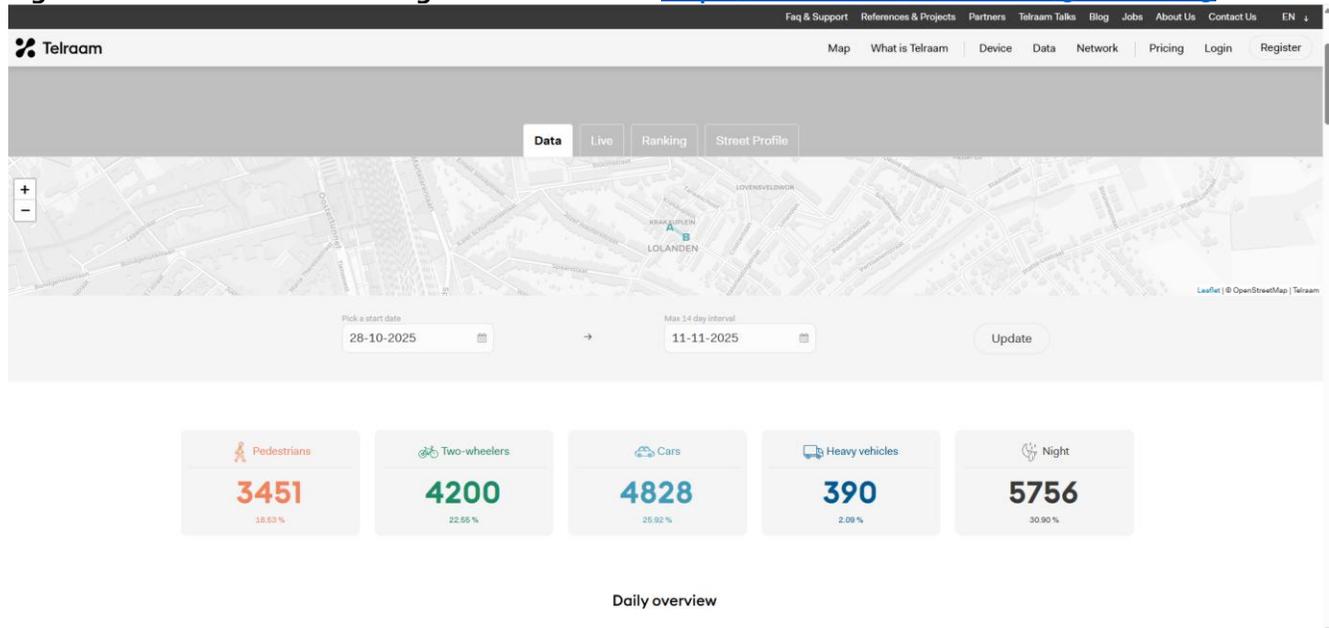


Figure 12: Telraam sensor reading information from <https://telraam.net/en/location/9000008629>



### 2.2.3 OpenAQ sensor readings

The OpenAQ plugin integrates OpenAQ air quality measurement data into a VCS UI application, offering users an interactive way to discover and visualize recent pollution observations directly on the map. It wraps configurable data request workflow, a feature info integration, and a toggleable sidebar/window UI. The plugin exposes a small configuration surface: a base proxy URL for OpenAQ requests (default: <https://urbreath.virtualcitymap.de/openaqproxy/>), a chart type (default line), and the number of past days to query (default 1). These values are merged with defaults at startup and serialized back only when deviating, ensuring lean persisted state.

On initialization, the plugin creates and registers a volatile OpenAQFeatureInfo view that enriches map feature interactions with measurement details (including station metadata and recent sensor values). Volatile marking signals that this view is transient and excluded from long-term persistence. Once the VCS app mounts, the plugin contributes a single toolbox action that toggles a dynamic left-slot window component. That window encapsulates user input (parameter, country selection, time span) and the action to add the requested OpenAQ data layer to the map; successful additions are communicated via localized success messaging.

Overall, the plugin provides:

- Seamless map-layer enrichment with authoritative air quality data.
- A clear, minimal configuration model with sensible defaults.
- A modular UI window paired with toolbox ergonomics via createToggleAction.
- Feature info augmentation for contextual, on-demand measurement insight.
- Full bilingual localization ready for report-ready distribution.

- Clean resource management and low persistence footprint through volatility marking and selective serialization.

This makes it a lightweight, maintainable extension point for environmental data visualization within the VCS ecosystem, with obvious growth paths (e.g., adding config editors, extending chart types, or broadening localization).

After fetching the data from OpenAQ, when clicking on an air quality point within the map, a compact information panel appears instantly, providing clear and accessible insights. It identifies the selected location or monitoring station, specifies the type of air quality measurement available—such as particulate matter or nitrogen dioxide—and includes the sensor’s name along with a brief description of what is being measured. If configured, the panel also displays a simple chart showing recent readings from the past few days, helping users quickly assess short-term trends.

This functionality allows users to stay within the map environment without needing to consult external sources. It supports rapid comparison between different locations, offers immediate feedback when data is unavailable, and presents information in a user-friendly format without technical jargon. The consistent interaction model—click, read, move, combined with multilingual support and future-proof design, makes it an intuitive and efficient tool for exploring urban air quality.

Figure 13. OpenAQ sensor reading for parameter PM2.5 in Pilsen LDT

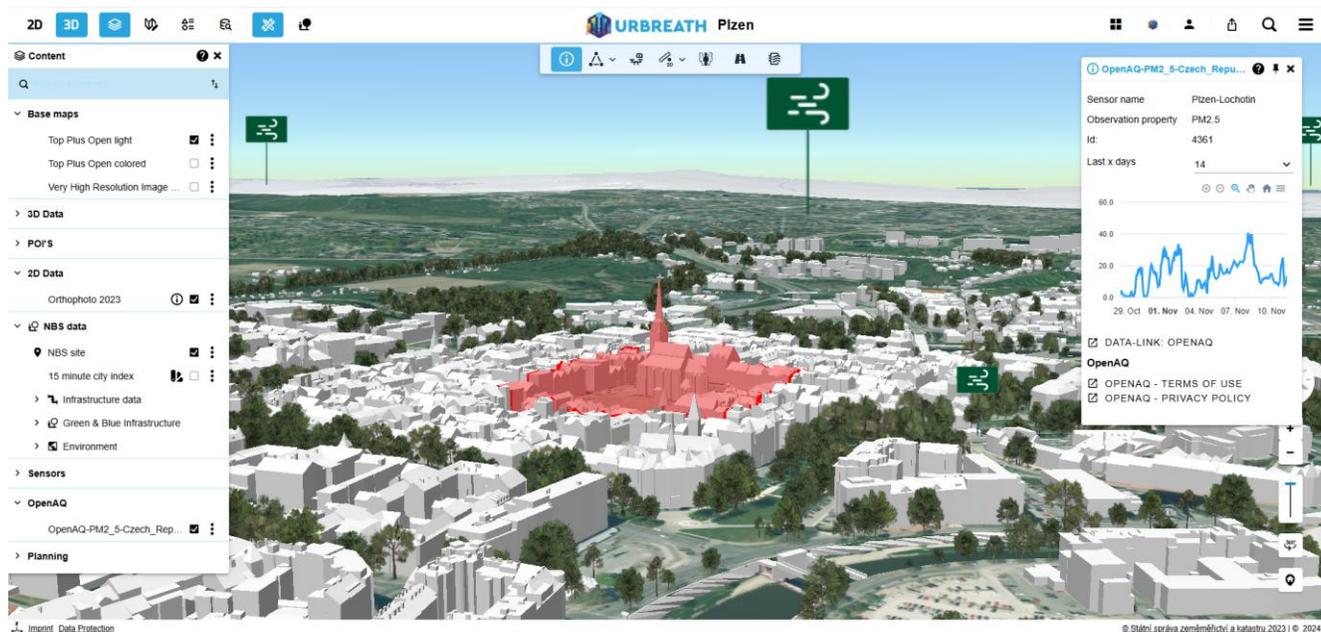
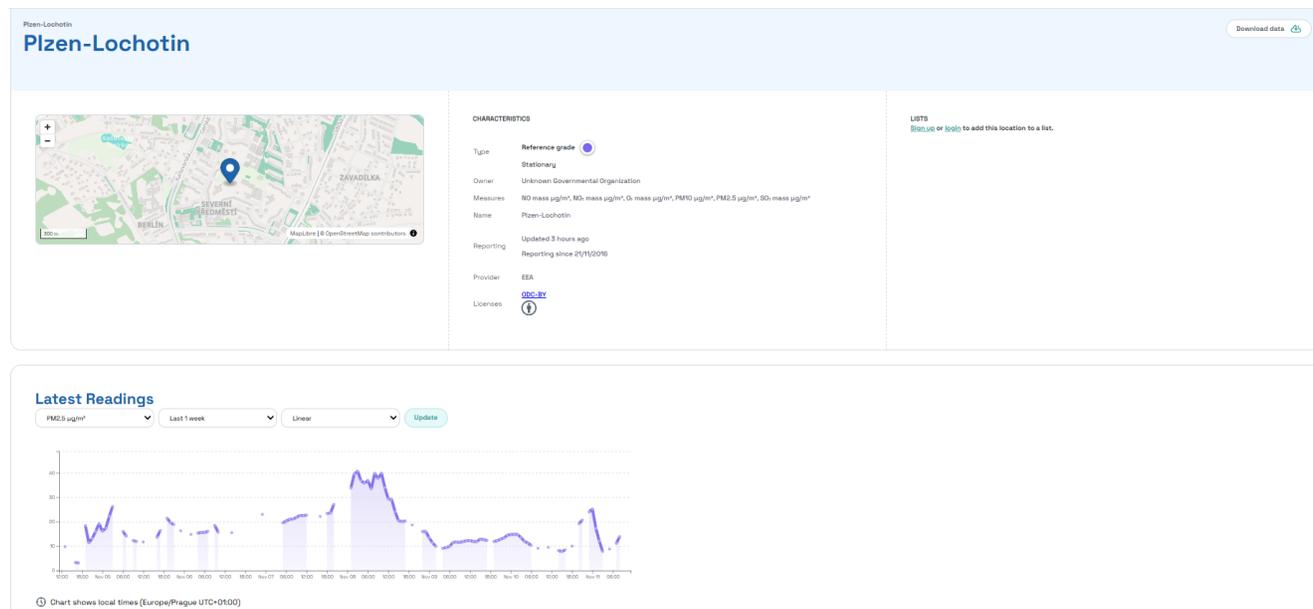


Figure 14. OpenAQ sensor reading displayed here: <https://explore.openaq.org/locations/4361>





Using the VC Planner, pilots can virtually plant new trees within the 3D city model. The viewer provides a selection of 26 different tree species, each available in young, middle-aged, and fully-grown variants. These newly placed trees can then be utilized in subsequent analyses, such as shadow simulations (see Section 2.2.5) and growth modeling (see Section 2.2.6), as illustrated in Figure 17 (left).

For BAF (Biotope Area Factor) calculations, pilots have two flexible options. They can either use the integrated NBS library to manually draw polygons representing elements like street greenery, rooftop vegetation, or permeable surfaces, or they can import existing features from external sources such as shapefiles or GeoJSON files—typically exported from CAD tools. Once imported, these features can be assigned to specific classes using the Feature Library Assignment, ensuring accurate categorization for BAF analysis. Figure 17 also illustrates the use of object libraries for planting trees (left), defining BAF areas (middle), and assigning library elements to imported features (right).

### 2.2.5 Shadow analysis

The Shadow Tool in VC Map is a specialized application that helps users analyze how shadows affect a selected area throughout the day. It simulates sunlight movement and calculates shadow coverage at user-defined intervals, such as every 15, 30, or 60 minutes. The tool also estimates temperature changes based on shadow coverage, surface materials, and environmental settings, providing realistic results for each time step.

The interface is user-friendly, offering step-by-step guidance and help sections. Results are visualized in clear charts and images, showing the shadow coverage changes over time. All findings can be exported as professional PDF reports or CSV files for documentation and presentation.

Designed for fast calculations, the tool keeps users informed with progress indicators and notifications. It is ideal for urban planners, environmental analysts, architects, and city officials who need to assess the impact of shadows on public spaces, microclimates, and energy usage. The Shadow Tool provides a comprehensive, customizable, and easy-to-use solution for visualizing and analyzing the effects of shadows in urban environments, supporting better planning and environmental decisions.

#### *Shadow analysis tool Capabilities Summary*

The Shadow Tool in VC Map is a specialized application designed to help users analyze how shadows affect a selected area throughout the day. Its main features and capabilities include:

#### **Shadow Simulation and Analysis**

- The tool simulates the movement of sunlight and calculates how much of a chosen area is covered by shadow at different times.
- Users can select the time interval for analysis (e.g., every 15, 30, or 60 minutes), allowing for flexible and detailed studies.

### ***User-Friendly Interface***

- The tool provides a simple and intuitive interface for drawing or entering the area to be analyzed.
- Step-by-step guidance and help sections are available to assist users.

### ***Visualization of Results***

- Results are presented in easy-to-read charts and images, showing shadow coverage changes over time.
- Pie charts and line graphs help users quickly understand the impact of shadows on their area of interest.

### ***Export and Documentation***

- All findings—including charts, images, and data tables—can be exported as a PDF report or CSV file for documentation, sharing, or presentation purposes.

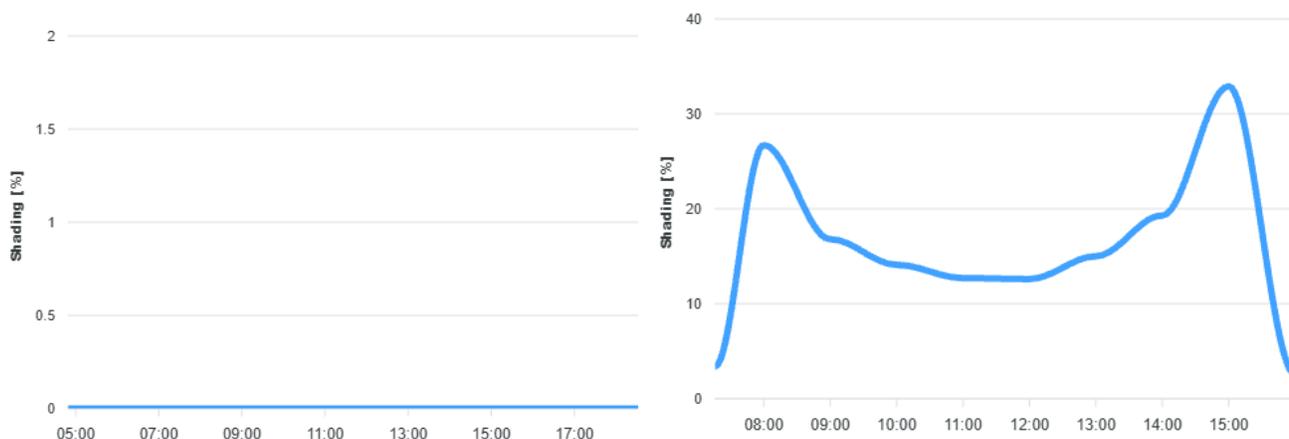
### ***Performance and Feedback***

- The tool is designed for fast calculations, with progress indicators and notifications to keep users informed during analysis.
- It is suitable for typical urban planning and environmental assessment tasks, but calculation time may vary depending on area size and chosen interval

**Figure 16: LDT situation for shadow analysis (left: without NBS planning; right: with NBS planning)**



Figure 17: Shadow analysis (left: without NBS planning and 3D buildings; right: with NBS planning)



### Interpretation of the shadow analysis result

The **second chart (Figure 17 with planning, right)** shows a clear variation in shading percentage throughout the day. There are two pronounced peaks: one in the early morning around 08:00, reaching approximately 27–28%, and another in the late afternoon around 15:00, peaking at about 32–33%. Between these peaks, shading levels remain relatively stable but lower, fluctuating between 12–18% from mid-morning to early afternoon. This pattern suggests that planned measures effectively manage shading during critical periods, reducing extremes and maintaining moderate levels during midday. In contrast, the **first chart (Figure 17 without planning, left)** indicates almost no shading impact across the entire time range. The shading percentage remains close to 0% from 05:00 to 17:00, with no visible peaks or fluctuations. This implies that without planning, shading is negligible, potentially leading to higher exposure during peak sunlight hours. Overall, the comparison highlights the significant role of trees in controlling shading levels, particularly during morning and afternoon periods when sunlight intensity is highest.

#### 2.2.5.1 KPI relation

The outcome of the tool relates to D5.1 – Annex V, page 112, CR-KPI10 (Increase Shaded areas) is relevant to Pilots:  
Leuven (FRC), Cluj-Napoca (FRC), Madrid (FRC), Parma (FLC) and Pilsen (FLC).

## 2.2.6 Growing Trees

As presented in D4.1 - Local Digital Twin and KPIs catalogue for urban NBSs - V1 D4.7 , chapter 4.5.9 The growing trees plugin simulates the linear growth of urban trees over a user-defined number of years, allowing users to adjust growth rates and visualize annual changes. It models transitions between tree age classes and includes special logic for lollipop trees, while excluding negative growth and environmental factors such as weather or soil conditions. The simulation produces detailed outputs on canopy coverage, oxygen production, CO<sub>2</sub> sequestration, water demand, and biomass, presented in both tabular and graphical formats. It also estimates the number of people supported by the oxygen produced. Users can generate PDF reports containing simulation data, visualizations, and screenshots. Charting and PDF generation libraries are integrated to support dynamic reporting. All calculations are based on scientifically grounded assumptions and constants, ensuring clarity, reproducibility, and transparency.

This plugin makes it easy to simulate and analyze tree growth in a selected area. Users can choose or upload geographic data, adjust growth settings, and run simulations to see how trees and their canopies develop over time. The results are shown visually and can be exported for further use, including maps and data files. The tool is designed to support planning and environmental analysis, helping users understand the impact of tree growth with simple controls and clear outputs.

Possible outputs of the plugin are:

- Visual maps of tree growth and canopy coverage
- GeoJSON files with tree locations and canopy shapes
- Raster files (GeoTIFF) for terrain, tree, and canopy data
- Summary tables and diagrams with key statistics
- Downloadable ZIP files with all relevant data
- PDF reports with images, tables, and results

**Figure 18: Result of baseline analysis (Tree canopy) for the NBS area in Leuven**



The tool counts the individual trees and calculates the canopy area for each tree species and also the overall canopy coverage. Based on a given area or the convex hull of all trees a canopy coverage can be calculated, see **Errore. L'origine riferimento non è stata trovata.** (right). There the crown area is calculated with  $\sim 5000\text{m}^2$  and the hull area is about  $11.500\text{m}^2$ . Thus as a result, the share of tree canopy

Figure 19: Tree canopy coverage at "Now" state



is in that case  $\sim 43\%$ .

Moreover, the tool enables users to simulate a fictive future state by selecting a number of years and a desired growth rate. It generates a baseline "now" state (**Errore. L'origine riferimento non è stata trovata.**), starting from the date the simulation is performed, and projects one or more future states

Figure 20: Tree canopy prediction for "in 5 years" state



up to the specified time horizon (see Figure 21). These future states can be used for comparative analysis, allowing users to evaluate changes in tree canopy and other metrics over time. Additionally, the projected states can serve as the basis for further visual or analysis assessments, such as shadow analysis, as described in chapter 2.2.5. Combining both tools in an analysis chain, would give pilots the ability to perform a shadow analysis for situation in X years, see **Errore. L'origine riferimento non è stata trovata.** Compared to Figure 17 right, the effect of grown trees in 5 years becomes obvious.

**Figure 21: Grown trees after 5 years and the result of a shadow-analysis on the right**



Figure 17, right shows the shading for the current planned configuration without additional growth. Here, shading starts near zero in the early morning, quickly climbs to about 25–28% by 08:00, then decreases steadily to around **12–15% during midday**. In the afternoon, shading rises again to approximately 30% before dropping sharply toward evening. Compared to the five-year scenario, the overall shading is lower and less consistent, indicating that future growth significantly improves coverage and reduces heat exposure during critical hours.

**Errore. L'origine riferimento non è stata trovata.** graph represents shading distribution throughout the day for a five-year growth scenario. Shading begins at approximately 20% in the early morning and rises sharply to around 38–40% by 07:00. After this peak, it gradually declines to about **25% around midday**, before increasing again in the afternoon to reach a second peak of roughly 42% at 16:30. This pattern reflects the influence of tree canopy growth on solar exposure, with higher shading during morning and late afternoon hours when the sun is lower in the sky.

### 2.2.6.1 KPI relation

The outcome of the tool relates to D5.1 – Annex V, page 110, BIO-KPI7 (Increase share of NBS area covered by tree canopy) is relevant to Pilots:

Leuven (FRC), Madrid (FRC), Parma (FLC) and Athens (FLC).

### 2.2.7 Small-scale BAF calculation

As presented in D4.1 - Local Digital Twin and KPIs catalogue for urban NBSs - V1

D4.7 , chapter 4.5.4 the BAF-Calculation plugin is integrated into the VC Map UI to compute the Biotope Area Factor (BAF), which measures the proportion of ecologically effective surfaces relative to total land area. It processes spatial data layers, typically GeoJSON, to create BAF-specific map layers, perform calculations, and aggregate results such as total and BAF-weighted areas. The plugin enhances user interaction through context menu integration and supports internationalization in English and German. Additional features include custom SVG icons for easy identification and robust lifecycle management for smooth operation. By enabling spatial analysis and visualization of ecological value, the plugin serves as a powerful tool for urban and environmental planning workflows.

Figure 22: NBS area in Leuven's LDT, showing the planned intervention and the usage of the surfaces



Figure 23: Result of the BAF area calculation for NBS area shown in Figure 22

November 11, 2025

BAF Calculation

### RESULTS OF THE BIOTOPE AREA FACTOR CALCULATION

The biotope area factor is a measure of the quality and quantity of biotopes in a specific area. It is calculated by dividing the area of the biotopes by the total area (sum of all individual areas) of the region. A higher value indicates better ecological quality.

Surface type	Area [m <sup>2</sup> ]	Weight	Biotope area [m <sup>2</sup> ]
Surfaces with vegetation, connected to the soil below	2120.11	1	2120.11
Sealed surfaces	3443.55	0	0.00
Semi-open surfaces	545.91	0.2	109.18
Greened surfaces	386.14	0.4	154.46
Rainwater infiltration	52.04	0.2	10.41
Total	6547.75		2394.15
Biotope area factor			0.37

Sum of all individual areas [m<sup>2</sup>]: 6547.75

Sum of all biotope areas [m<sup>2</sup>]: 2394.15

**Biotope area factor: 0.37**

#### 2.2.7.1 KPI relation

The BAF calculation tool relates to D5.1 – Annex V, page 110, BIO-KPI2 and thus is relevant to Pilots: Leuven (FRC), Cluj-Napoca (FRC), Pilsen (FLC), Parma (FLC) and Athens (FLC).

### 3 Digital Twin Maturity Model

The **Digital Twin Maturity Model** from DUET is a framework designed to guide cities and organizations in developing and implementing digital twins. Digital twins are virtual representations of real-world systems, processes, or environments that help in analyzing, simulating, and improving decision-making. This model identifies key enablers—such as people, governance, and technology—and provides a structured path to assess the current state ("As Is") and plan for future goals ("To Be").

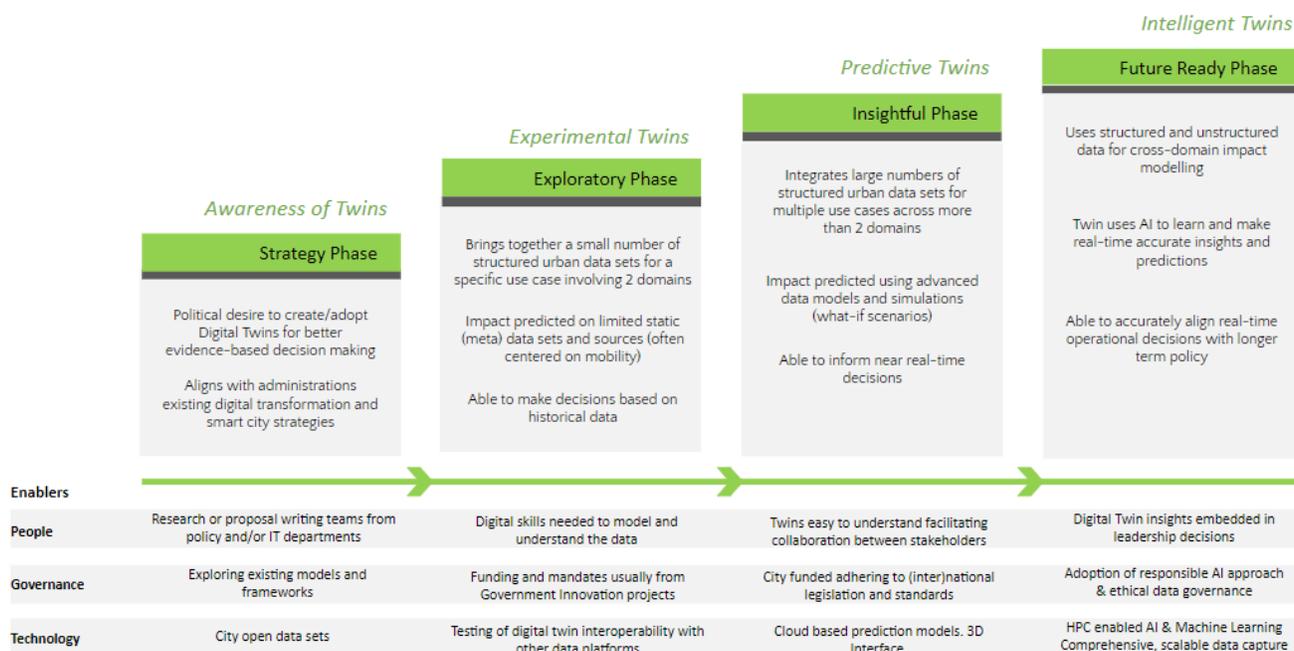
The model outlines progressive phases of maturity:

- 1. Awareness Phase:** Initial exploration of digital twin concepts, typically focused on raising awareness and strategizing for adoption.
- 2. Experimental Twins:** Early-stage implementation using limited datasets, often historical, to explore potential policy impacts.
- 3. Predictive Twins:** More advanced systems incorporating real-time or near-real-time data across multiple domains for informed decision-making.
- 4. Intelligent Twins:** Fully mature systems leveraging AI and advanced analytics to enable accurate real-time predictions and automated decision-making.

This model serves as both a diagnostic and planning tool, helping stakeholders design effective strategies for adopting digital twins tailored to their unique needs and aspirations.

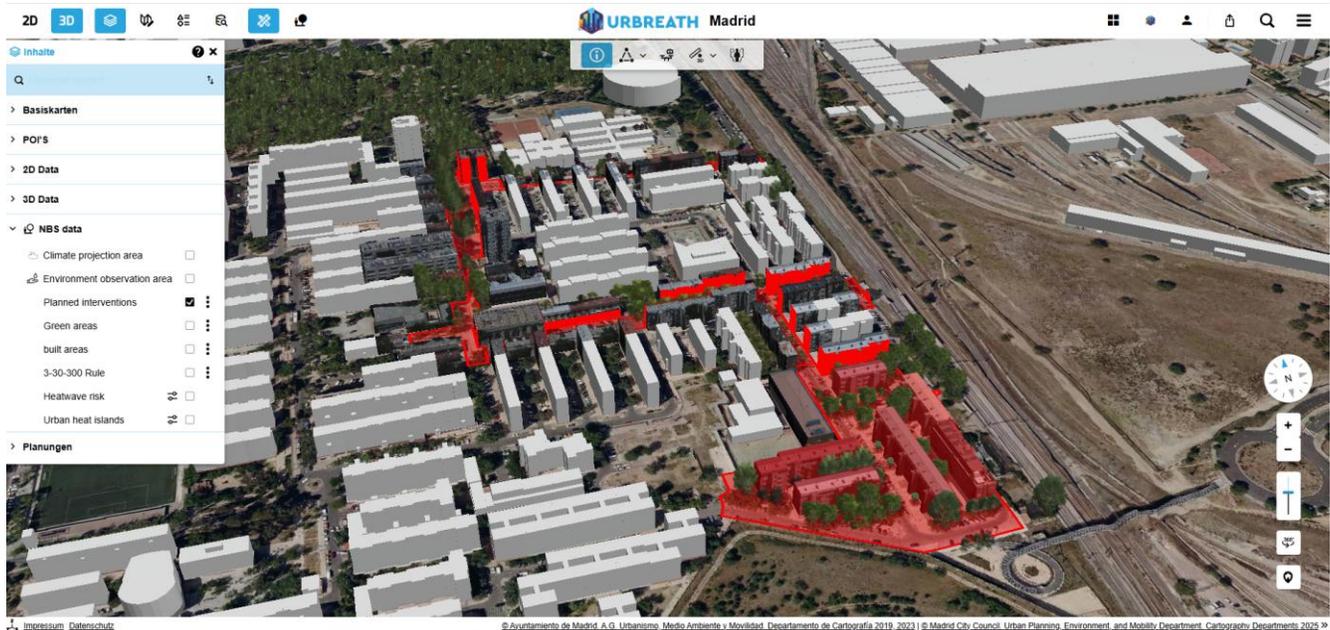
For more detailed insights, you can visit the [Digital Urban Twins website](#).

**Figure 24: Duet - Digital Twin Maturity Model**



## 4 FRC – Madrid

Figure 25: LDT of Madrid-Villaverde, showing the NBS intervention area



Besides the 3D datasets, mentioned in D4.1 the LDT comprises additionally a total of 34 spatial layers (see Table 7), organized into multiple formats to support diverse analytical needs. Among these, three layers are provided as GeoJSON, representing vector-based features such as climate projection areas, environmental observation zones, and planned interventions. In addition, two layers use VectorTile formats, delivering tiled vector data for green areas and built areas to enable efficient visualization of large-scale spatial structures. The remaining 29 layers are Cloud Optimized GeoTIFF (COGLayers), which form the core of the dataset and include high-resolution raster data for climate-related analyses. These raster layers cover thematic aspects such as the 3-30-300 rule, annual heatwave risk maps for 2021 to 2023, and an extensive series of urban heat island observations across multiple months and years. This composition highlights a strong emphasis on raster data for climate and heat vulnerability assessments, complemented by vector layers that provide structural and planning context.

These layers serve as a comprehensive foundation for urban climate analysis and planning. The GeoJSON and VectorTile layers provide detailed vector representations of structural elements such as green spaces, built environments, and planned interventions, which are essential for spatial planning and policy development. The extensive collection of raster layers enables high-resolution modeling of climate-related phenomena, including heatwave risk and urban heat island dynamics over time. By integrating these datasets, stakeholders can assess environmental vulnerabilities, monitor changes, and design targeted strategies to enhance urban resilience. This combination of vector and raster data

supports both strategic decision-making and operational applications, ranging from climate adaptation planning to real-time visualization in digital platforms.

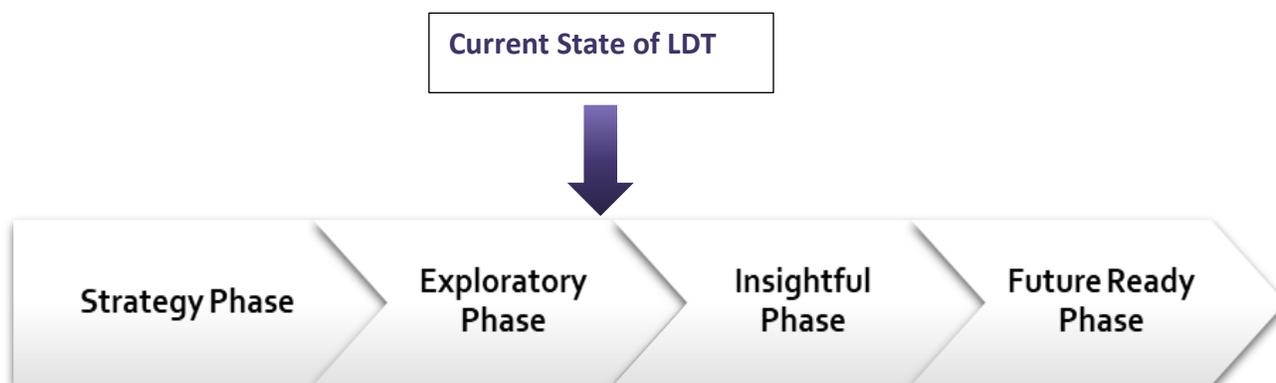
Table 7: Overview of NBS related datasets in Madrids LDT

Layer Name	Title	Format / Type
Climate	Climate projection area	GeoJSONLayer
Environment	Environment observation area	GeoJSONLayer
planned_inter	Planned interventions	GeoJSONLayer
Green_area	Green areas	VectorTileLayer (FlatGeobuf)
Built_area	Built areas	VectorTileLayer (StaticGeoJSON)
3-30-300	3-30-300 Rule	COGLayer (Raster)
heatwave2021	Heatwave potential risk 2021	COGLayer (Raster)
heatwave2022	Heatwave potential risk 2022	COGLayer (Raster)
heatwave2023	Heatwave potential risk 2023	COGLayer (Raster)
Urban heat islands (multiple entries)	Urban heat islands YYYY-MM	COGLayer (Raster)

**Notes:**

- The **Urban heat islands** layers have multiple entries for different months and years (2021–2023), each with its own raster file.
- Formats include **GeoJSON**, **FlatGeobuf**, **StaticGeoJSON**, and **COGLayer (Cloud Optimized GeoTIFF)**.

Figure 26: Estimated current State of Madrid-LDT acc. to Maturity Model



### ***Usage of LDT***

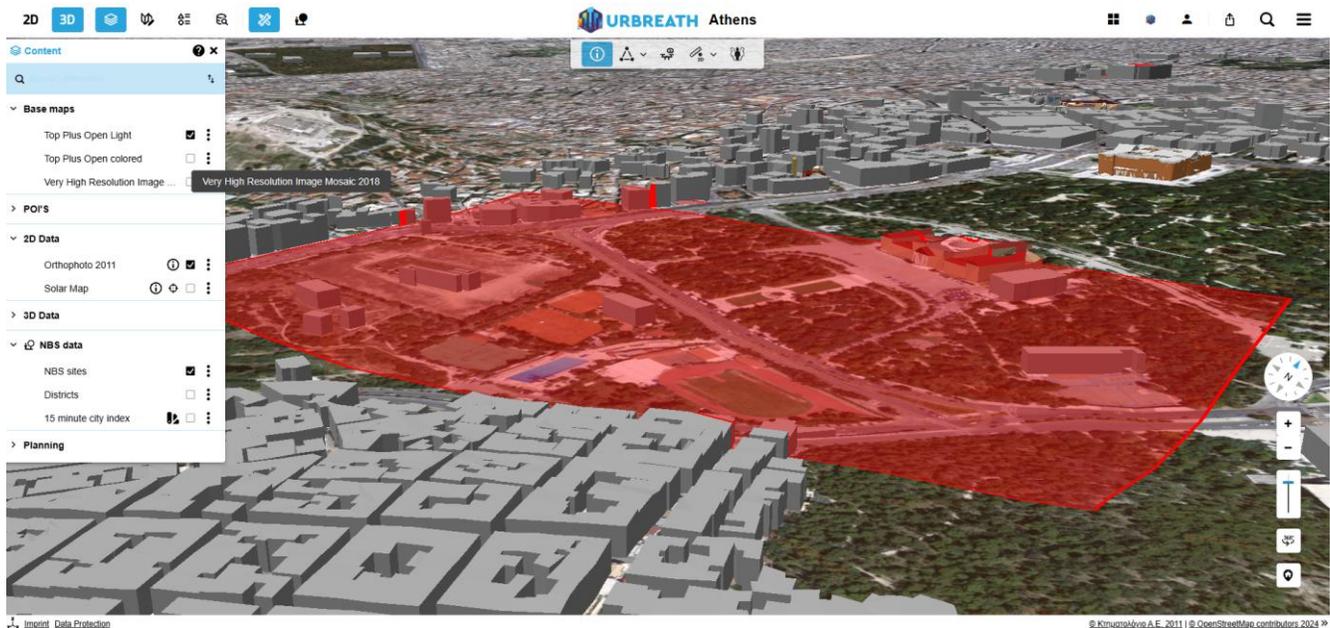
In Madrid, the LDT is currently being integrated into an ongoing cycle of capacity-building sessions with the interdepartmental municipal team. This process is essential for assessing the usability of the URBREATH digital tools and ensuring that the LDT complements—rather than duplicates—the existing analytical and planning platforms already in use across the Madrid City Council. The goal of these sessions is to refine workflows, clarify data needs, and identify how the 3D model and associated layers facilitate climate adaptation and urban planning analysis.

In parallel, Madrid team plans to incorporate the final co-designed interventions into the digital twin. This step will allow more precise impact assessment, detailed visualization, and structured feedback between designers, municipal technicians, and Living Lab participants. By embedding the final designs into the LDT environment, the city will be able to generate comparative simulations and strengthen evidence-based decision-making for future urban climate actions.

## 4.1 Follower Cities

### 4.1.1 Athens

Figure 27: LDT of Athens, showing the NBS intervention area



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Athens defines a total of 3 spatial layers, organized into two main formats. Specifically, there are 2 GeoJSON layers and 1 VectorTile layer, reflecting a strong focus on vector-based data for urban analysis and planning. The GeoJSON layers include:

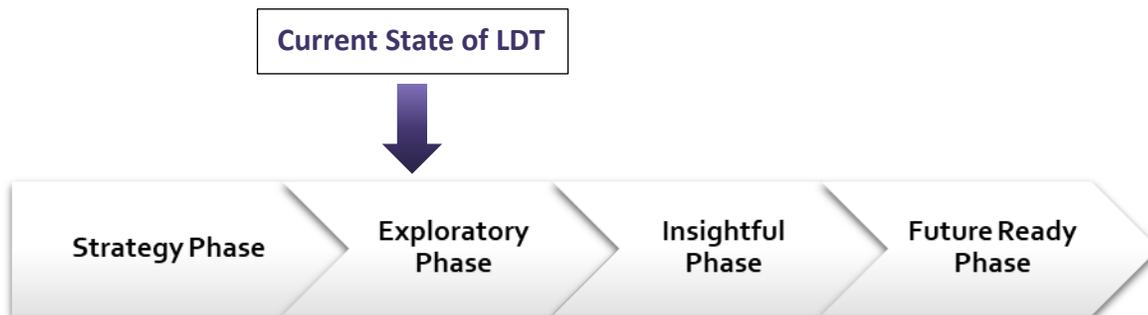
- nbs-site – NBS sites: Represents locations of nature-based solutions within Athens.
- districts – Districts: Provides administrative or planning boundaries for the city.

The VectorTile layer is:

walkability\_urb – 15-minute city index: A tiled vector dataset that supports detailed analysis of walkability across multiple categories, such as education, groceries, parks, healthcare, and entertainment. This layer includes multiple declarative styles for thematic visualization, enabling insights into accessibility within different time ranges (e.g., <5 min, 5–10 min, etc.).

Unlike datasets dominated by raster layers, this Athens dataset emphasizes vector data, which is ideal for interactive mapping and dynamic styling. The inclusion of a comprehensive walkability index highlights the dataset’s utility for urban mobility and accessibility studies, while the NBS sites and district boundaries provide essential context for planning and sustainability initiatives.

Figure 28: Estimated current State of Athens-LDT acc. to Maturity Model



### ***Integration of Co-Designed Interventions and Advanced Impact Assessment in Athens LDT***

The Athens team is preparing to integrate the finalized co-designed interventions into the city’s Local Digital Twin (LDT) platform. This process will specifically include the calculation of the Biotope Area Factor as well as analyses of Urban Heat Island effects. By conducting these calculations and projecting their outcomes into the future, the team aims to deepen the understanding of how these interventions may influence urban environmental conditions over time.

Incorporating the final designs into the LDT environment will enable more accurate assessment of impacts, providing the ability to visualize outcomes in detail. This structured approach will facilitate effective feedback loops among designers, municipal technicians, and Living Lab participants, ensuring that all stakeholders remain engaged and informed throughout the assessment process.

Through these advancements, Athens will be able to conduct comparative simulations for different scenarios, thereby enhancing the city’s capacity for evidence-based decision-making. Ultimately, this will support the planning and implementation of future urban climate actions with greater precision and confidence.

## 4.1.2 Parma

Figure 29: LDT of Parma, showing the 3 NBS intervention area



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Parma defines a total of 10 spatial layers, organized into two main formats: GeoJSON and VectorTile. Specifically, there are 5 GeoJSON layers and 5 VectorTile layers, reflecting a balanced mix of vector-based data for urban analysis and planning.

### GeoJSON Layers

*nbs-site* – NBS sites: Represents locations of nature-based solutions within Parma.

*quartieri* – Districts: Provides administrative or planning boundaries.

*neighbourhood* – NBS neighbourhoods: Defines neighborhood-level areas relevant to NBS planning.

*parks* – Parks & Gardens: Highlights green spaces and recreational areas.

*water* – Open water: Represents water bodies within the city.

### VectorTile Layers

*landcover* – Land coverage: A tiled vector dataset for detailed land use and cover classification.

*streets* – Street footprints: Provides Street network geometry for mobility analysis.

*walkability\_urb* – 15-minute city index: Includes multiple thematic styles for accessibility to services like education, groceries, parks, healthcare, and entertainment.

*urbreath\_parma\_walkability* – (URBREATH) 15-minute city index: A specialized version of the walkability index for advanced urban mobility studies.

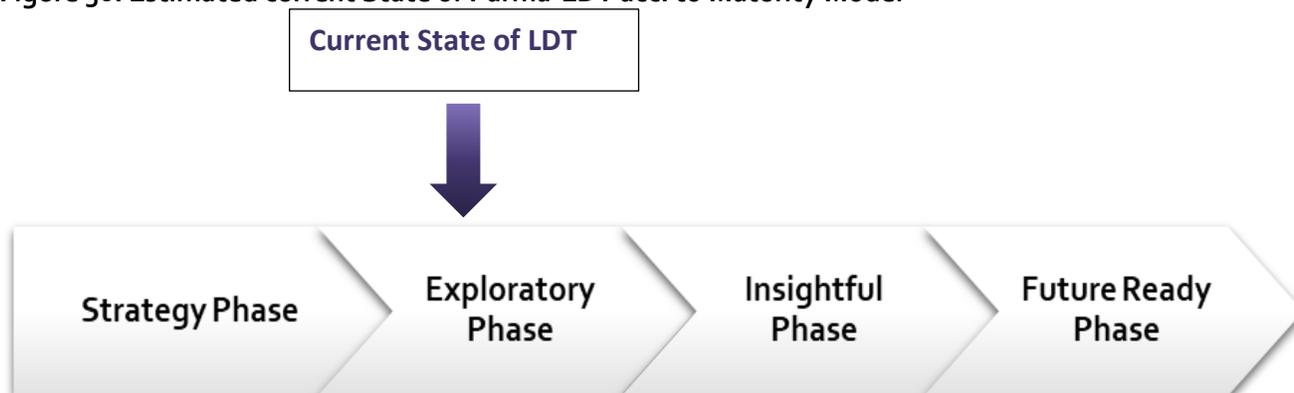
*green\_areas* – Vegetation types: Offers thematic classification of green spaces.

**Table 8: Overview of NBS related datasets in Parmas LDT**

Layer Name	Title	Format / Type
<b>nbs-site</b>	NBS sites	GeoJSONLayer
<b>quartieri</b>	Districts	GeoJSONLayer
<b>neighbourhood</b>	NBS neighbourhoods	GeoJSONLayer
<b>parks</b>	Parks & Gardens	GeoJSONLayer
<b>water</b>	Open water	GeoJSONLayer
<b>landcover</b>	Land coverage	VectorTileLayer
<b>streets</b>	Street footprints	VectorTileLayer
<b>walkability_urb</b>	15-minute15-minute city index	VectorTileLayer
<b>urbreath_parma_walkability</b>	(URBREATH) 15-minute city index	VectorTileLayer

This dataset emphasizes vector data for interactive mapping and thematic analysis, with a strong focus on walkability and accessibility metrics. The inclusion of detailed land cover and street network layers supports urban planning, mobility studies, and sustainability assessments. The GeoJSON layers provide essential context for green infrastructure and water management, while the VectorTile layers enable efficient visualization and dynamic styling for large-scale spatial datasets.

**Figure 30: Estimated current State of Parma-LDT acc. to Maturity Model**



**Usage of LDT**

During the Living Lab, the city will use the 3D model as a central tool to present the intervention area and clearly illustrate the simulation scenario. Through the three-dimensional visualization, it will be possible to compare the expected effects on urban areas before and after the adoption of NBS,

assessing the projected transformations across different scenarios. This approach will allow participants to easily understand both the proposed intervention and the benefits it can generate, making the experience more engaging, intuitive, and accessible even for those who are not familiar with technical or design tools (e.g. planar view).

The use of the 3D model is intended to support a more open and inclusive participation process: being able to concretely see the effects of the NBS helps people express informed opinions, participate actively in decision-making, and contribute comments and suggestions based on a clear perception of the impacts on the territory.

In addition to the participatory workshops, the model will also be used internally across the different municipal departments. Its function will be to support the visualization and understanding of ongoing interventions, improving interdepartmental communication and exchange of information.

## 5 FRC – Leuven

Figure 31: LDT of Leuven, showing the NBS intervention area



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Leuven integrates multiple geospatial layers designed for urban analysis, climate resilience, and sustainability planning. These layers are categorized by format and purpose:

### **GeoJSON Layers (5)**

*Climate* – Represents the climate projection area for Leuven. Intended for visualizing and analyzing climate-related zones and their impact on urban planning.

*Environment* – Defines the environment observation area, supporting monitoring of pollution and environmental indicators.

*Infiltration Model Spatial Outputs (GeoJSON)* – The infiltration prediction model generates spatially-explicit GeoJSON layers containing infiltration rate predictions across user-defined areas within a study region.

These layers are produced through spatial analysis covering a specified extent (e.g., 5 km × 5 km area around a center point) under configurable weather conditions and scenario parameters. The model generates predictions at regularly spaced grid points covering the entire analysis area, with grid resolution configurable by the user depending on the desired spatial detail.

Each point feature in the GeoJSON includes the predicted infiltration rate (mm/hr), coordinates in both WGS84 (for web mapping compatibility) and Belgian Lambert 72 (original projection), grid cell size information, and Nature-Based Solution (NBS) scenario identifiers. When comparing multiple scenarios (such as different NBS interventions or seasonal conditions), the layers can be exported either as separate files per scenario or as unified files containing predictions for all scenarios at each grid point, facilitating direct performance comparison.

Each GeoJSON also includes the analysis configuration including spatial extent (bounding box in both coordinate systems), grid resolution, generation timestamp, weather parameters, model version, and statistical summaries (mean, minimum, maximum infiltration rates across the study area).

These layers support spatially explicit assessment of infiltration capacity under various conditions, identification of areas with high or low infiltration potential, and evaluation of different NBS intervention strategies.

*Use Case:*

GeoJSON layers provide detailed vector geometries for thematic mapping and spatial queries. They are ideal for dashboards, environmental monitoring, and scenario simulations.

### **VectorTile Layer (1)**

*walkability\_urb* – Represents the 15-minute city index, a metric for accessibility to essential services within walking distance. This layer supports urban mobility analysis and sustainable city design.

*Use Case:*

VectorTile layers enable efficient rendering of large-scale datasets at multiple zoom levels, making them suitable for interactive maps and performance-critical applications.

### **COG Raster Layers (9+)**

*3-30-300* – Encodes the 3-30-300 rule for urban greenery (3 trees visible, 30% canopy cover, 300m to green space). Used for assessing compliance with urban greening standards.

*Urban Heat Islands (Sentinel-2) – Monthly raster layers* (e.g., 20220200T0000000\_Leuven\_suhi\_sentinel\_s2\_\_whole\_day\_visual) visualize surface urban heat island intensity across different months and years. These layers support climate adaptation strategies and heat mitigation planning.

*Use Case:*

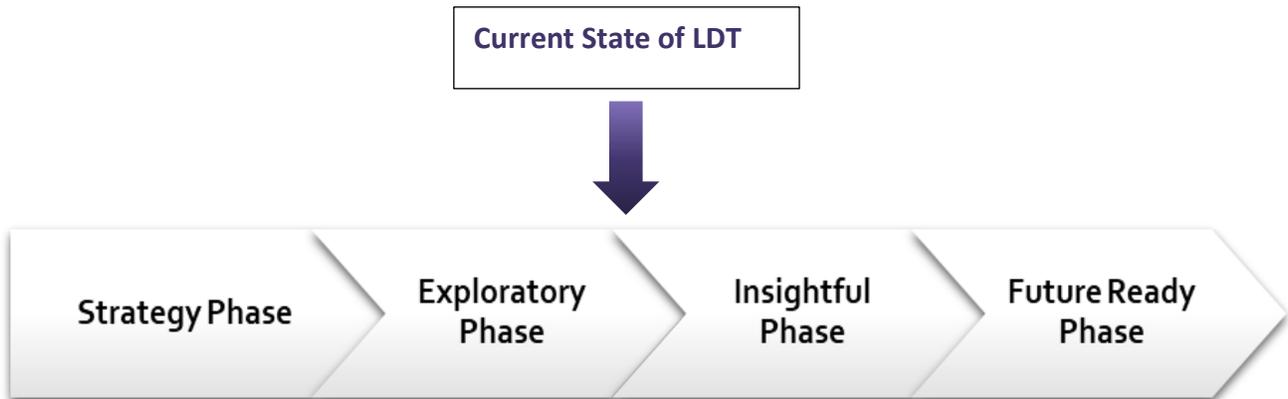
COG (Cloud Optimized GeoTIFF) layers are optimized for streaming large raster datasets, enabling fast visualization and analysis of climate and environmental phenomena.

The combination of these layers provides a comprehensive toolkit for Climate resilience planning (heat islands, climate projections), Environmental monitoring (pollution, infiltration), Urban sustainability (walkability, green infrastructure) and Policy compliance (like 3-30-300 rule).

**Table 9: Overview of Leuven's NBS related datasets in the LDT**

Layer Name	Title	Format / Type
Climate	Climate projection area	GeoJSONLayer
Environment	Environment observation area	GeoJSONLayer
infiltration_spring	Water infiltration (typical spring)	GeoJSONLayer
infiltration_summer	Water infiltration (summer storm)	GeoJSONLayer
infiltration_winter	Water infiltration (winter rain)	GeoJSONLayer
walkability_urb	15-minute city index	VectorTileLayer
3-30-300	3-30-300 Rule	COGLayer
20220200T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2022-02	COGLayer
20220300T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2022-03	COGLayer
20220400T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2022-04	COGLayer
20220500T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2022-05	COGLayer
20220600T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2022-06	COGLayer
20220700T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2022-07	COGLayer
20221100T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2022-11	COGLayer
20230200T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2023-02	COGLayer
20230300T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2023-03	COGLayer
20230500T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2023-05	COGLayer
20230600T000000_Leuven_suhi_sentinel_s2__whole_day_visual	Urban heat islands 2023-06	COGLayer

Figure 32: Estimated current State of Leuven-LDT acc. to Maturity Model

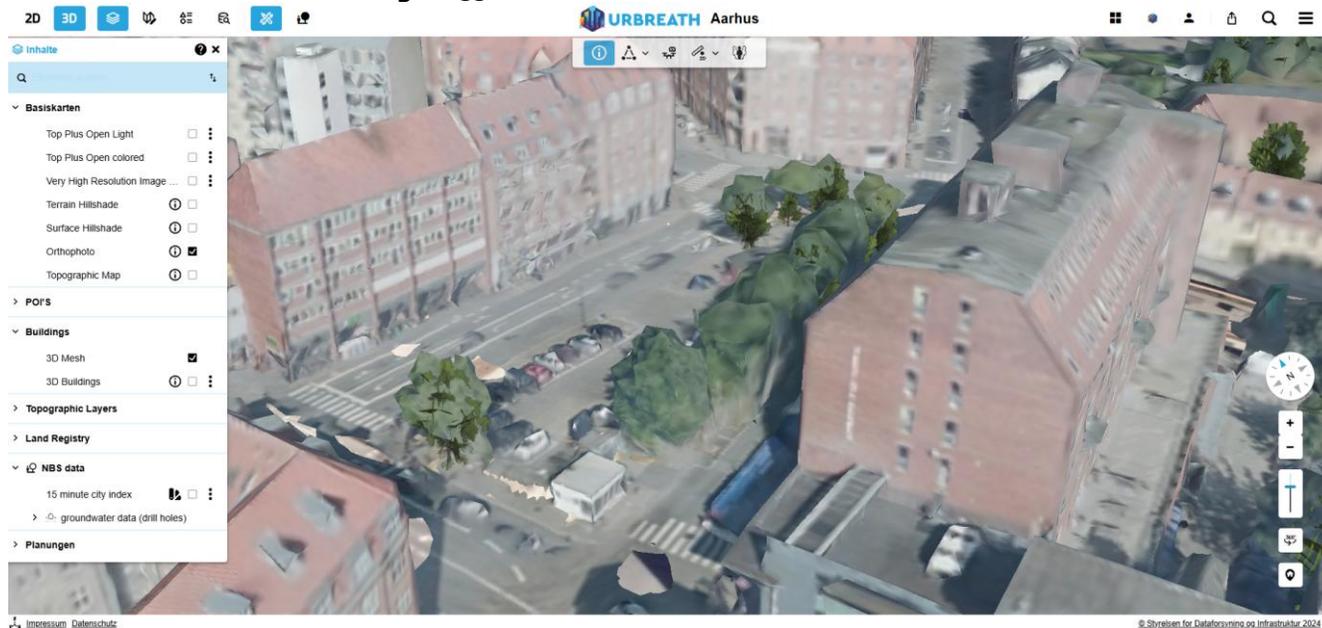


### ***Usage of LDT***

The 3D model has been adapted to each FRC, including Leuven, enabling a standardized framework for simulating and comparing urban environments before and after the implementation of Nature-Based Solutions (NBS). In Leuven, Living Labs (LLs) actively participated in defining scenario parameters, ensuring that the simulated changes reflect local priorities and community input. This participatory approach has allowed the team to assess and report on the effects of NBS adoption, providing clear visualizations and data-driven insights into the model’s impact on urban heat islands and other relevant urban phenomena.

## 5.1 Follower City – Aarhus

Figure 33: NBS intervention area in Aarhus LDT



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Aarhus defines a total of 15 spatial layers, organized into two main formats. Specifically, there is 1 VectorTile layer and 14 WMS layers, reflecting a strong emphasis on raster-based thematic maps for groundwater monitoring, complemented by a vector-based layer for urban analysis.

### VectorTile Layer

*walkability\_urb* – 15-minute city index: A tiled vector dataset supporting detailed analysis of walkability across multiple categories such as education, groceries, parks, healthcare, and entertainment. This layer includes multiple declarative styles for thematic visualization, enabling insights into accessibility within different time ranges (e.g., <5 min, 5–10 min, etc.). The purpose of this dataset is Urban mobility and accessibility studies as well as supporting sustainable city planning.

### WMS Layers

These layers provide thematic maps for groundwater data, drilling, water supply, and quality assurance:

*Aarhus\_drillholes\_stoffgroup* – Analyses on substance groups: Represents grouped chemical analyses for groundwater samples.

*Aarhus\_drillholes\_stoff* – Analyses on substances: Detailed chemical analysis of groundwater.

*jupiter\_anlaegsanalyser* – Plant analyses on substances: Monitoring contamination in plant facilities.

*jupiter\_grp\_anlaegsanalyser\_test* – Plant analyses on substance groups: Experimental grouping of plant analysis data.

*jupiter\_boringer\_ws* – Danish drilling: Locations and attributes of drilling sites.

*jupiter\_anlaeg\_ws* – Danish facilities: Infrastructure related to groundwater management.

*jupiter\_bor\_anl\_koblet* – Drilling plant connected: Links between drilling sites and facilities.

*jupiter\_bor\_vandfors\_almen\_ws* – Danish water supply wells: Wells for public water supply.

*jupiter\_bor\_vandfors\_andre\_ws* – Danish water supply wells, the rest: Additional wells for water supply.

*mc\_pejling* – Water levels: Measurements of groundwater levels.

*mc\_vandtype* – Water types: Classification of groundwater types.

*jupiter\_bor\_cyklogram* – Cyklograms: Specialized groundwater data visualization.

*mc\_kvalitetssikring\_grp* – Quality control substance group level: Ensures analytical data integrity at group level.

*mc\_kvalitetssikring* – Quality assurance of analytical data: General quality assurance for groundwater data.

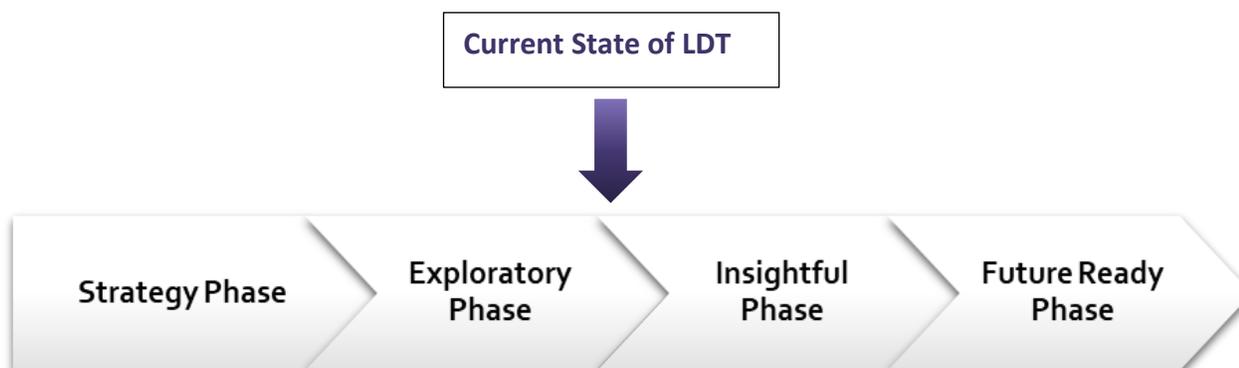
### **Summary**

Unlike datasets dominated by vector layers, the Aarhus LDT emphasizes WMS layers for groundwater and environmental monitoring, ensuring robust support for hydrogeological analysis and compliance. The inclusion of the walkability index highlights the dataset's utility for urban planning and accessibility studies, while the groundwater layers provide essential context for sustainability and resource management.

**Table 10: Datasets used in Aarhus LDT**

Name	Title	Format
walkability_urb	15-minute city index	VectorTileLayer
Aarhus_drillholes_stoffgroup	Analyses on substance groups	WMSLayer
Aarhus_drillholes_stoff	Analyses on substances	WMSLayer
jupiter_anlaegsanalyser	Plant analyses on substances	WMSLayer
jupiter_grp_anlaegsanalyser_test	Plant analyses on substance groups	WMSLayer
jupiter_boringer_ws	Danish drilling	WMSLayer
jupiter_anlaeg_ws	Danish facilities	WMSLayer
jupiter_bor_anl_koblet	Drilling plant connected	WMSLayer
jupiter_bor_vandfors_almen_ws	Danish water supply wells	WMSLayer
jupiter_bor_vandfors_andre_ws	Danish water supply wells, the rest	WMSLayer
mc_pejling	water levels	WMSLayer
mc_vandtype	water types	WMSLayer
jupiter_bor_cyklogram	cyklograms	WMSLayer
mc_kvalitetssikring_grp	Quality control substance group level	WMSLayer
mc_kvalitetssikring	Quality assurance of analytical data	WMSLayer

**Figure 34: Estimated current State of Aarhus-LDT acc. to Maturity Model**



### **Usage of LDT**

For Aarhus, the 3D model has been tailored to reflect the specific characteristics of the city, ensuring its relevance for local stakeholders. Living Labs (LLs) have actively utilized the model to simulate and visualize urban changes, enabling a comparative assessment of conditions before and after the implementation of Nature-Based Solutions (NBS). These scenarios were collaboratively defined through participatory processes, allowing the model to support evidence-based decision-making and foster community engagement in evaluating the impact of NBS measures.

## 6 FRC – Tallinn

Figure 35: LDT of Tallinn, looking at the NBS site



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Tallinn brings together a diverse collection of spatial layers designed to support urban climate analysis, environmental monitoring, and resilience planning. The data is organized into three main formats: GeoJSON for vector-based observation areas, COG for raster datasets such as heat island analysis, and WMS for thematic maps covering noise, forest dynamics, flooding, and land cover. This structure reflects a strong emphasis on raster and service-based layers, complemented by vector data for delineating study areas.

Two GeoJSON layers define the spatial extent of climate projection and environmental observation zones in Tallinn. These vector datasets serve as the foundation for integrating thematic analyses and dashboards, enabling targeted assessments of climate impacts and pollution patterns.

Raster data is represented through Cloud Optimized GeoTIFF (COG) layers, most notably the 3-30-300 rule map, which visualizes compliance with urban greening standards. In addition, a series of monthly heat island layers derived from Sentinel-2 imagery provide detailed insights into urban thermal dynamics from April 2023 through October 2024. These layers allow temporal comparisons of heat stress across seasons, supporting strategies for mitigating urban heat effects.

The largest share of the dataset consists of WMS layers, which deliver thematic maps for multiple domains. Soil and CORINE land cover layers offer essential context for ecological and land-use analysis, while street maps provide reference geometry for urban planning. Noise mapping is particularly

comprehensive, with layers segmented by source—street traffic, highways, railways, industry, and flight paths—and further differentiated by time periods such as day, evening, night, and combined indicators (Lden). This granularity enables precise evaluation of acoustic environments and supports compliance with noise regulations.

Forest-related layers capture canopy height and changes in forest cover, including seasonal updates and cumulative trends, which are critical for biodiversity and carbon sequestration assessments. Flooding layers complement this by identifying hazard zones and risk areas, including coastal flood hazards and regions with a 10% annual probability of inundation. These datasets are indispensable for risk management and climate adaptation planning.

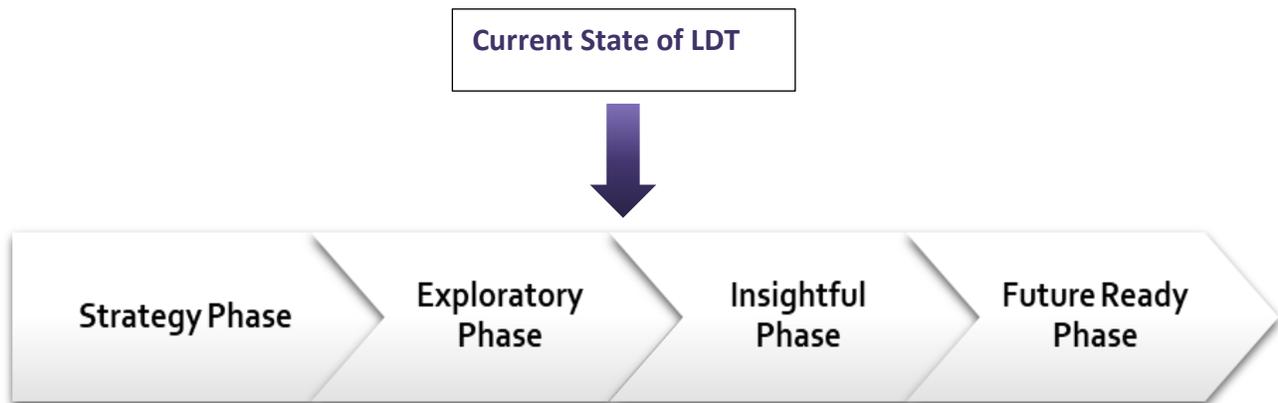
Overall, the Tallinn NBS dataset prioritizes environmental and climate resilience through a rich combination of raster and service-based layers. Heat island and noise maps underscore its relevance for sustainable urban development, while forest and flood data provide a broader ecological and risk perspective. Together, these layers form a robust foundation for integrated analysis, policy-making, and strategic interventions aimed at enhancing urban livability and sustainability.

**Table 11: Overview of Tallinn NBS related datasets**

Name	Title	Format
<b>Climate</b>	Climate projection area	GeoJSONLayer
<b>Environment</b>	Environment observation area	GeoJSONLayer
<b>3-30-300</b>	3-30-300 Rule	COGLayer
<b>20230400T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2023-04	COGLayer
<b>20230500T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2023-05	COGLayer
<b>20230600T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2023-06	COGLayer
<b>20230700T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2023-07	COGLayer
<b>20240300T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-03	COGLayer
<b>20240400T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-04	COGLayer
<b>20240500T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-05	COGLayer
<b>20240600T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-06	COGLayer
<b>20240700T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-07	COGLayer
<b>20240800T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-08	COGLayer
<b>20240900T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-09	COGLayer
<b>20241000T000000_Tallin_suhi_sentinel_s2_whole_day_visual</b>	Urban heat islands 2024-10	COGLayer
<b>soil_map</b>	soil thematic map	WMSLayer
<b>corine</b>	CORINE land cover	WMSLayer
<b>streets</b>	Streets	WMSLayer
<b>heatIslandsJune</b>	June, 27, 2024	WMSLayer
<b>heatIslandsMay</b>	May, 19 & 26, 2024	WMSLayer

<b>noise_24</b>	noise (Lden)	WMSLayer
<b>noise_day</b>	noise (Lday)	WMSLayer
<b>noise_evening</b>	noise (Levening)	WMSLayer
<b>noise_night</b>	noise (Lnight)	WMSLayer
<b>noise_highway_day</b>	noise daytime	WMSLayer
<b>noise_highway_night</b>	noise nighttime	WMSLayer
<b>noise_railway_24</b>	noise (Lden)	WMSLayer
<b>noise_railway_day</b>	noise (Lday)	WMSLayer
<b>noise_railway_evening</b>	noise (Levening)	WMSLayer
<b>noise_railway_night</b>	noise (Lnight)	WMSLayer
<b>noise_industry_24</b>	noise (Lden)	WMSLayer
<b>noise_industry_day</b>	noise (Lday)	WMSLayer
<b>noise_industry_evening</b>	noise (Levening)	WMSLayer
<b>noise_industry_night</b>	noise (Lnight)	WMSLayer
<b>noise_flight_24</b>	noise (Lden)	WMSLayer
<b>noise_flight_day</b>	noise (Lday)	WMSLayer
<b>noise_flight_evening</b>	noise (Levening)	WMSLayer
<b>noise_flight_night</b>	noise (Lnight)	WMSLayer
<b>noise_all_24</b>	noise (Lden)	WMSLayer
<b>noise_all_day</b>	noise (Lday)	WMSLayer
<b>noise_all_evening</b>	noise (Levening)	WMSLayer
<b>noise_all_night</b>	noise (Lnight)	WMSLayer
<b>canopy2024spring</b>	canopy height spring 2024	WMSLayer
<b>cover2024spring</b>	change in forest cover	WMSLayer
<b>forestcoverchange</b>	total change in forest cover	WMSLayer
<b>flood_hazard_area_10perc</b>	Flood hazard area (P=10%)	WMSLayer
<b>coastal_flood_hazard_area_10perc</b>	Coastal flood hazard (P=10%)	WMSLayer
<b>flood_risk_areas</b>	Flood risk areas (PSFRA)	WMSLayer

Figure 36. Estimated current State of Tallinn-LDT acc. to Maturity Model

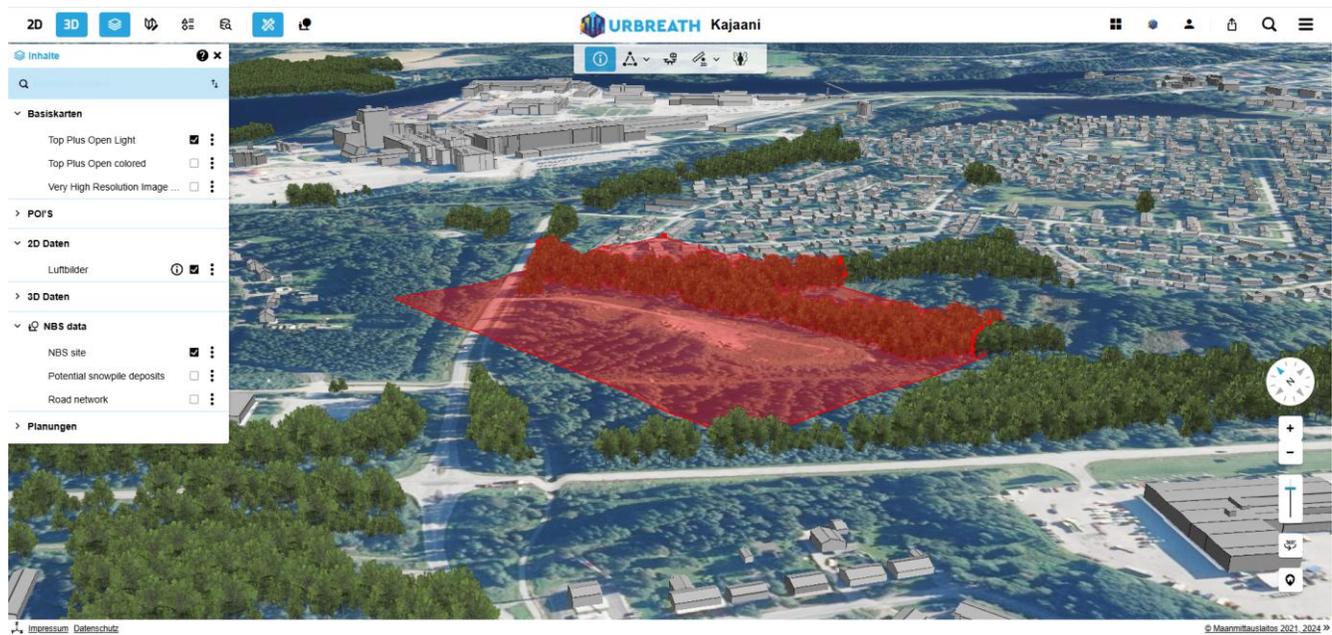


### *Usage of LDT*

In Tallinn, the 3D model has been carefully adapted to reflect the unique urban characteristics and data availability of the city, ensuring relevance for local flood risk assessment and planning. Living Labs (LLs) utilized the model to simulate and compare urban scenarios both before and after the implementation of nature-based solutions (NBS), with participatory processes guiding the definition of these scenarios. This approach enabled stakeholders to visualize the tangible impacts of NBS measures on urban flood resilience, supporting evidence-based decision-making and fostering collaborative adaptation strategies.

## 6.1 Follower City – Kajaani

Figure 37: LDT of Kajaani, looking at the NBS site



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Kajaani on spatial layers that support winter urban management and infrastructure planning. The data is structured into three main formats: GeoJSON layers for defining specific areas and deposits, VectorTile layers for scalable visualization of road networks and snowpile locations, and declarative styles for thematic representation of attributes such as area size and street classification.

Two GeoJSON layers form the core of the NBS related section. The first represents the NBS site boundary, providing a clear delineation of the intervention area for nature-based solutions. The second layer identifies potential snowpile deposit locations, which are critical for managing snow clearance operations during winter months. These vector datasets enable precise mapping and integration with other urban planning tools.

Complementing these are VectorTile layers that enhance performance and scalability for large datasets. One VectorTile layer mirrors the snowpile deposit information in FlatGeobuf format, optimized for tiled rendering and efficient data access. Another VectorTile layer represents the road network, offering detailed geometry for streets and associated attributes. This layer supports advanced styling for road hierarchy and functional classification, which is essential for traffic management and infrastructure maintenance.

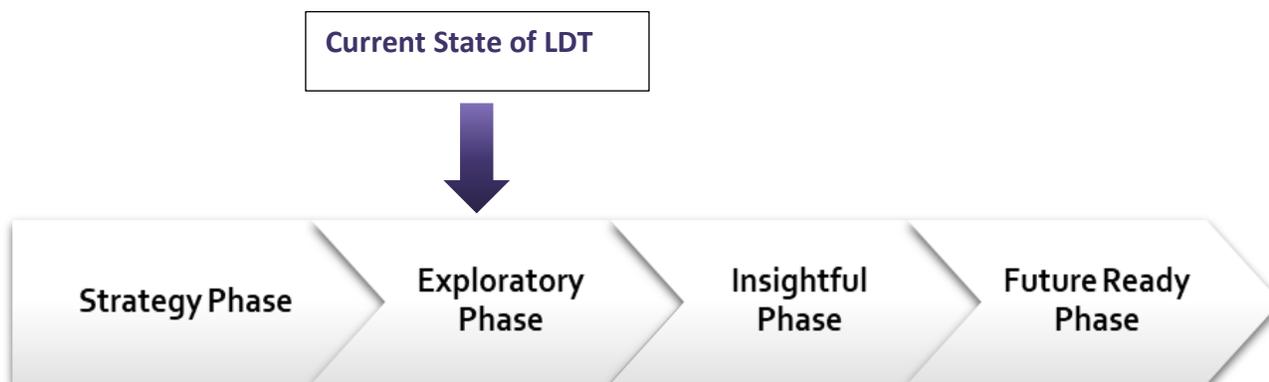
The dataset also includes rich declarative styling configurations. These styles categorize roads by type, ranging from main roads and regional streets to pedestrian paths and service connections, and apply color schemes and stroke widths to reflect their functional importance. Additional styles classify snow pile areas by size, enabling quick visual assessment of available space for snow storage. Such thematic visualization aids decision-making in urban operations and resource allocation.

Overall, the Kajaani NBS datasets emphasizes operational efficiency and resilience in cold climates. By integrating snow management layers with detailed street networks and applying dynamic styling, the dataset provides a robust foundation for planning, monitoring, and optimizing winter urban services. Its combination of vector precision and tiled scalability ensures both analytical depth and practical usability for municipal authorities and planners.

**Table 12: Overview of Kajaanis NBS related datasets**

Name	Title	Format
snowpile	Potential snowpile deposits	GeoJSONLayer
site	NBS site	GeoJSONLayer
streets	Road network	VectorTileLayer

**Figure 38: Estimated current State of Kajaanis-LDT acc. to Maturity Model**



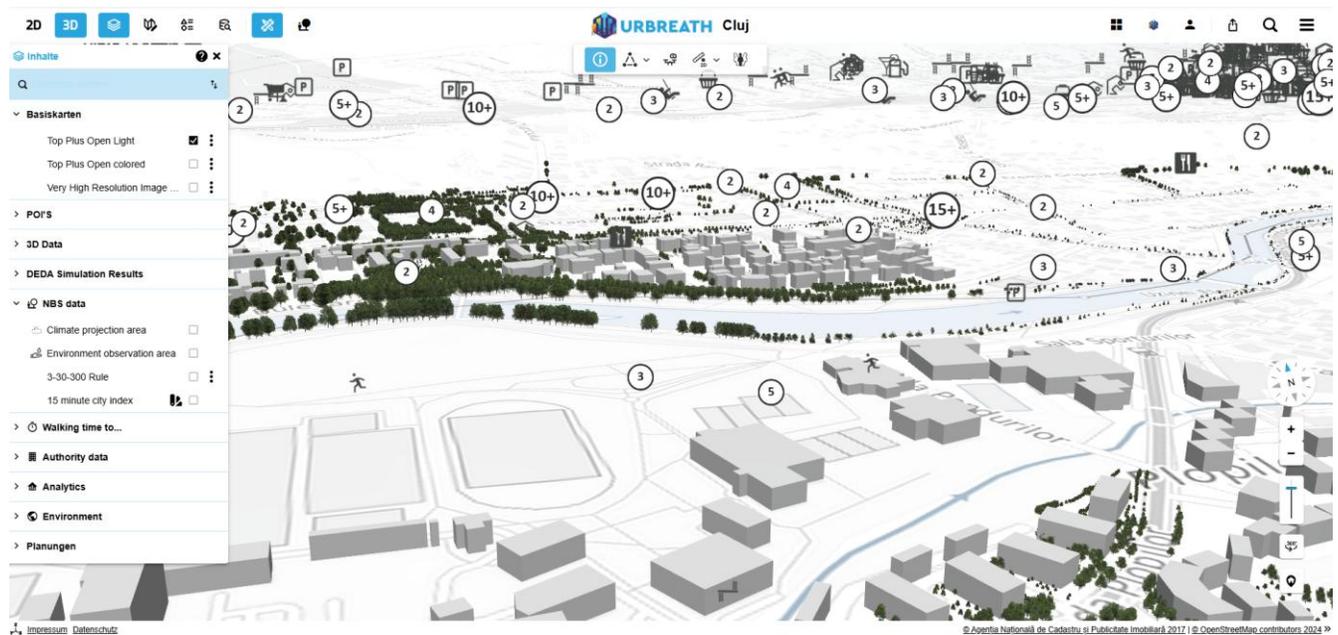
**Usage of LDT**

The 3D model developed for Kajaani has been successfully adapted, enabling local living labs (LLs) to simulate and assess the impacts of nature-based solutions (NBS) measures. Through participatory processes, scenarios were defined and the model facilitated a comparative analysis of urban areas before and after the implementation of NBS interventions. This approach allowed stakeholders to visualize changes in urban resilience and environmental quality, thereby supporting informed decision-making and collaborative planning.

The usage of the Digital Twin in Kajaani centers on the seamless integration of diverse spatial datasets to support urban analysis and informed decision-making. By aggregating GeoJSONLayer data for snowpile deposits and NBS sites with the VectorTileLayer road network, the Digital Twin enables dynamic visualization and real-time monitoring of urban infrastructure and environmental assets. This integration facilitates scenario modeling, such as forecasting the impact of snow accumulation on mobility, and supports optimization of maintenance operations. Additionally, the Digital Twin's architecture allows stakeholders to overlay multiple data sources, enhancing the accuracy of service accessibility assessments and the evaluation of sustainability initiatives. As a result, the Kajaani Digital Twin serves as a vital platform for collaborative planning and operational efficiency, aligning with the city's goals for resilience and smart city development.

## 7 FRC - Cluj-Napoca

Figure 39: LDT of Cluj-Napoca, looking at one of their NBS sites



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Cluj is an extensive collection of spatial layers designed to support urban sustainability, mobility, and environmental resilience. It combines multiple data formats, including GeoJSON for vector delineations, VectorTile layers for scalable thematic mapping, and COG layers for raster-based analysis. This structure enables detailed insights into accessibility, land use, infrastructure, and ecological conditions.

GeoJSON layers define key observation areas such as climate projection zones and environmental monitoring regions. Additional GeoJSON datasets provide walking-time isochrones to essential services like schools, pharmacies, police stations, platforms, and places of worship. These layers are fundamental for evaluating accessibility and equity in urban service provision.

VectorTile layers dominate the dataset, offering a wide range of thematic information. They include demographic and analytical layers such as population distribution, population projections, and traffic forecasts, as well as specialized indices like the Mai index and network analysis. Infrastructure-related layers cover roads, railways, subway lines and stations, bicycle routes, pedestrian corridors, and modernization proposals. Environmental layers detail land cover types, including forest cover, cropland, grassland, wetlands, and tree coverage for 2020, alongside dynamic indicators such as forest gain and forest loss. Additional thematic layers address flood risk scenarios, green infrastructure proposals, and nightlight intensity, which serves as a proxy for urban activity and energy use.

A notable feature of the NBS related section is the inclusion of the walkability index, represented as a VectorTile layer with multiple declarative styles. This index supports the concept of the 15-minute city by analyzing accessibility to amenities such as education, groceries, healthcare, parks, entertainment, and post offices within defined walking time ranges. The dataset also integrates a raster-based COG layer for the 3-30-300 rule, which evaluates compliance with urban greening standards, reinforcing the focus on livability and climate adaptation.

Complementary layers provide detailed authority data, including administrative boundaries, marginalized urban areas, and strategic corridors like the Somes River route and metropolitan beltline. These layers are essential for urban governance and planning, enabling multi-scale analysis from neighborhood-level accessibility to regional infrastructure development.

Overall, the Cluj NBS section offers a comprehensive foundation for sustainable urban planning. Its combination of accessibility metrics, environmental indicators, and infrastructure data supports integrated strategies for mobility, climate resilience, and ecological restoration. By leveraging both vector and raster formats, the dataset ensures analytical depth and operational flexibility, making it a powerful tool for decision-makers and researchers focused on creating inclusive and resilient urban environments.

**Table 13: Overview of Cluj’s NBS related datasets**

Name	Title	Format
<b>Climate</b>	Climate projection area	GeoJSONLayer
<b>Environment</b>	Environment observation area	GeoJSONLayer
<b>Walking time to Police</b>	Walking time to Police	GeoJSONLayer
<b>Walking time to Pharmacy</b>	Walking time to Pharmacy	GeoJSONLayer
<b>Walking time to School</b>	Walking time to School	GeoJSONLayer
<b>Walking time to platform</b>	Walking time to Platform	GeoJSONLayer
<b>Walking time to places of Worship</b>	Walking time to places of Worship	GeoJSONLayer
<b>Amenities</b>	Amenities	GeoJSONLayer
<b>Population</b>	Population	VectorTileLayer
<b>Mai index</b>	Mai index	VectorTileLayer
<b>Network analysis</b>	Network analysis	VectorTileLayer
<b>Proximities School-Building</b>	Proximities school ↔ building	VectorTileLayer
<b>Public transport</b>	Public transport	VectorTileLayer
<b>Administrative areas</b>	Administrative areas	VectorTileLayer
<b>Build areas</b>	Build areas	VectorTileLayer
<b>Bypass belts</b>	Bypass belts	VectorTileLayer
<b>Easybox</b>	Easybox	VectorTileLayer

<b>Education</b>	Education	VectorTileLayer
<b>Electric charging</b>	Electric charging	VectorTileLayer
<b>Bycicle routes</b>	Bicycle routes	VectorTileLayer
<b>Railway</b>	Railway	VectorTileLayer
<b>Roads</b>	Roads	VectorTileLayer
<b>Flood_1</b>	Average Scenario Flooding	VectorTileLayer
<b>Flood_potential</b>	Significant Flood Potential	VectorTileLayer
<b>Green_prop</b>	Green proposals	VectorTileLayer
<b>Infra_prop</b>	Infrastructure proposals	VectorTileLayer
<b>Major_cyc</b>	Major cycling routes	VectorTileLayer
<b>mar_urban</b>	Marginalized urban areas	VectorTileLayer
<b>metro_beltline</b>	Metro beltline	VectorTileLayer
<b>metro_connecting</b>	Metro connection	VectorTileLayer
<b>metro_nodes</b>	Metro nodes	VectorTileLayer
<b>metro_cycl_corridor</b>	Metro cycling corridors	VectorTileLayer
<b>road_modern</b>	Road modernization	VectorTileLayer
<b>pedest_bike</b>	Cycling and Pedestrian	VectorTileLayer
<b>Pop_proj</b>	Population projection	VectorTileLayer
<b>rail_stations</b>	Railway stations	VectorTileLayer
<b>traf_forecast</b>	Traffic Forecast 2030	VectorTileLayer
<b>subway_stations</b>	Subway stations	VectorTileLayer
<b>subway_lines</b>	Subway lines	VectorTileLayer
<b>somesul</b>	Somesul	VectorTileLayer
<b>somesul_area</b>	Somesul area	VectorTileLayer
<b>somesul_route</b>	Somesul route	VectorTileLayer
<b>forestloss</b>	Forest loss	VectorTileLayer
<b>water</b>	Open water	VectorTileLayer
<b>wetland</b>	Wetlands	VectorTileLayer
<b>sparse</b>	Bare & Sparse vegetation	VectorTileLayer
<b>build</b>	Build areas	VectorTileLayer
<b>forest</b>	Forest cover 2000	VectorTileLayer
<b>forestgain</b>	Forest gain	VectorTileLayer
<b>cropland</b>	Cropland	VectorTileLayer
<b>grassland</b>	Grassland	VectorTileLayer
<b>treecover2020</b>	Tree coverage 2020	VectorTileLayer
<b>nightlights</b>	Night Lights	VectorTileLayer
<b>3-30-300</b>	3-30-300 Rule	COGLayer
<b>walkability_urb</b>	15-minute city index	VectorTileLayer

### Sensorintegration into LDT of Cluj:

Figure 40: Air quality measurements in Cluj-Napoca



The Cluj sensor section focuses on real-time environmental and mobility monitoring through sensor-based layers. It integrates multiple SensorThings layers and GeoJSON data streams to capture dynamic observations such as air quality, noise levels, and light intensity. These layers are essential for urban analytics, enabling continuous assessment of environmental conditions and traffic patterns.

Two SensorThings layers provide EU-wide air quality measurements for PM2.5 and PM10, supporting

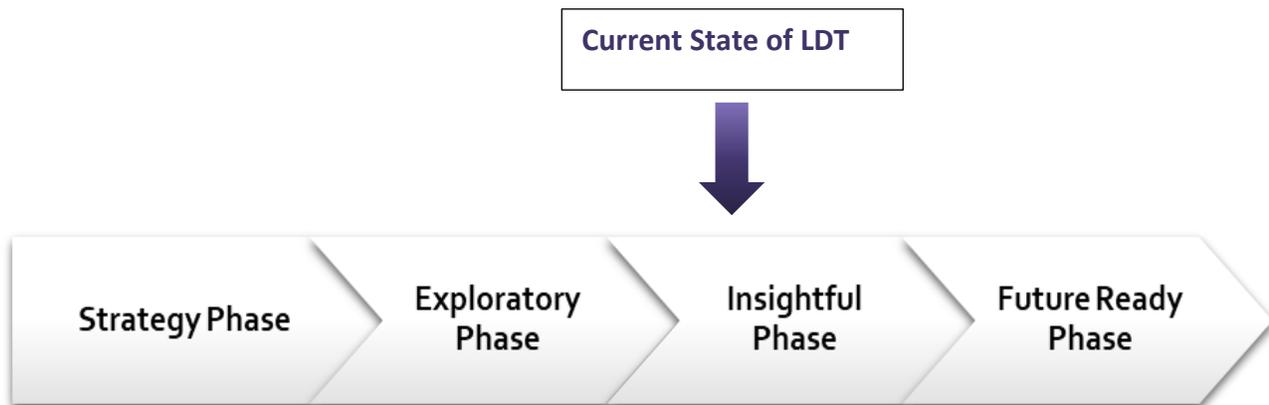
compliance with European environmental standards and informing health-related policies. Additional SensorThings layers monitor noise and light from CitiObs, offering insights into urban livability and energy efficiency. These datasets are particularly valuable for understanding the impact of traffic and artificial lighting on public spaces.

The dataset also includes a GeoJSON layer dedicated to air quality observations within Cluj, sourced from local sensors. This layer complements regional and EU-level data, ensuring granular visibility into pollution hotspots and supporting targeted interventions. FeatureInfo configurations enable interactive charts and dashboards, facilitating real-time visualization and trend analysis.

Styling configurations for traffic-related observations (Telraam) and environmental indicators allow thematic representation of sensor data, such as vehicle counts, pedestrian flows, and noise intensity. These visualizations enhance interpretability and support decision-making for mobility planning and noise mitigation strategies.

Overall, the Cluj sensor dataset emphasizes real-time monitoring and interoperability. By combining EU-scale and local observations, it provides a robust foundation for adaptive urban management, environmental health monitoring, and smart city initiatives.

Figure 41: Estimated current State of Cluj’s-LDT acc. to Maturity Model

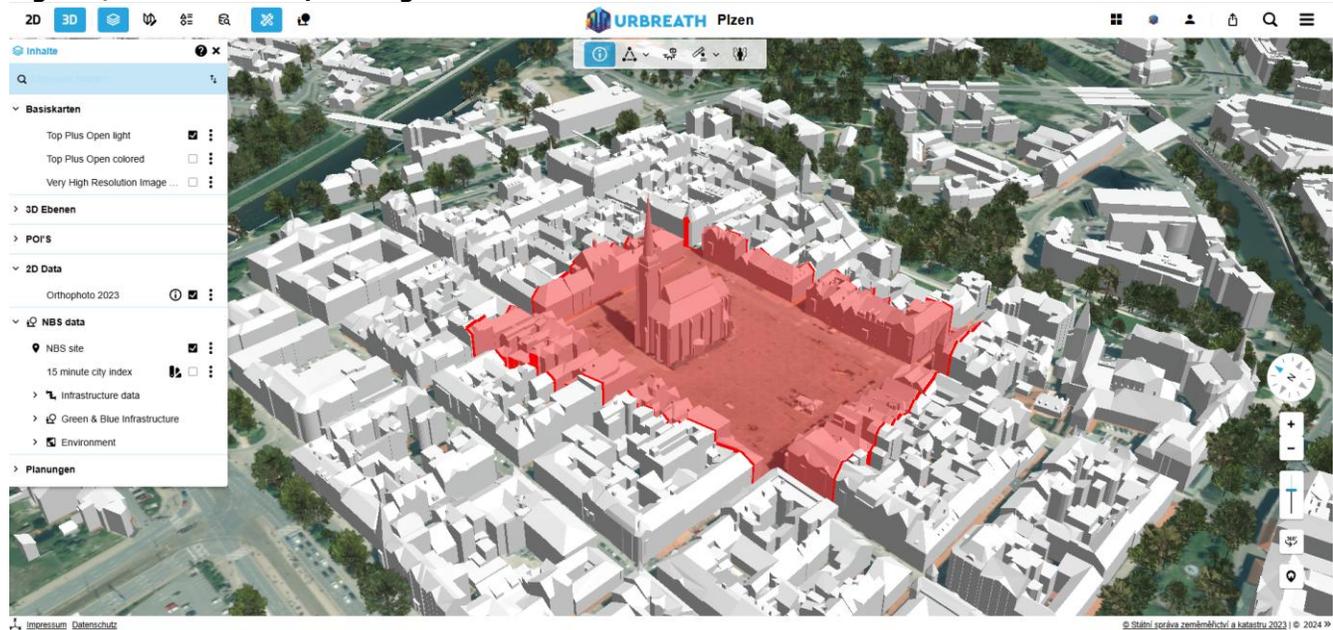


**Usage of LDT**

For Cluj-Napoca, the 3D model has been adapted to reflect the unique urban characteristics of the city. Local Living Labs (LLs) actively utilize the model to compare simulated effects on urban areas before and after the implementation of Nature-Based Solutions (NBS) measures. These assessments are conducted within scenarios that are collaboratively defined through participatory processes, allowing stakeholders to visualize and analyze the impact of NBS interventions on environmental and mobility indicators. The integration of real-time sensor data further enhances the accuracy and responsiveness of these simulations, supporting informed decision-making for urban sustainability and health. Beyond its technical integration, the Local Digital Twin (LDT) in Cluj-Napoca is leveraged as an interactive platform for collaborative urban planning and stakeholder engagement. The LDT enables city officials, researchers, and community members to simulate the effects of proposed interventions, such as new green spaces or mobility adjustments, in a shared digital environment. Through scenario analysis, users can assess the projected outcomes of different strategies, visualize potential improvements in air quality or traffic flow, and iteratively refine plans based on real-time sensor feedback. This dynamic and participatory use of the LDT fosters transparency and supports evidence-based policy development, aligning with the city’s broader goals for sustainable urban transformation.

## 7.1 Follower City – Pilsen

Figure 42: LDT of Pilsen, looking at their NBS site



Besides the 3d datasets, mentioned in D4.1 the LDT - NBS related section for Plzeň integrates a diverse range of spatial layers to support urban sustainability, infrastructure management, and environmental monitoring. It combines GeoJSON layers for detailed vector delineations, VectorTile layers for scalable thematic visualization, and WMS layers for service-based infrastructure data. This structure enables comprehensive analysis of green infrastructure, walkability, pollution sources, and essential utilities.

GeoJSON layers define key thematic areas such as parks and gardens, urban greenery, public spaces, and forested regions. These layers provide a granular view of green and blue infrastructure, supporting biodiversity planning and recreational space management. Additional GeoJSON datasets capture environmental indicators, including air quality measurements, weather stations, and pollution sources categorized by intensity. These datasets are essential for monitoring environmental health and guiding mitigation strategies.

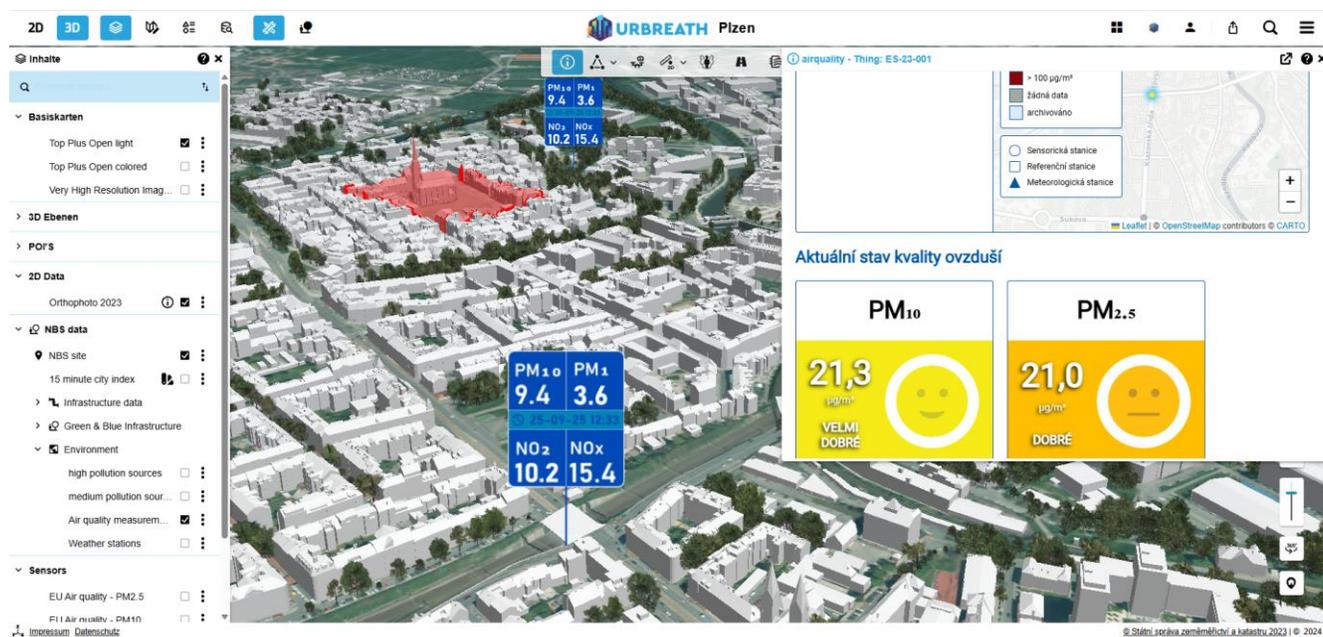
VectorTile layers complement this by offering scalable representations of meadows, open water bodies, and the walkability index, which evaluates accessibility to amenities within the framework of the 15-minute city concept. The walkability layer includes multiple declarative styles for thematic visualization, enabling detailed analysis across categories such as education, groceries, healthcare, parks, entertainment, and post offices. This supports urban mobility studies and sustainable city planning. WMS layers form the backbone of infrastructure monitoring, covering wastewater, fresh water, telecommunication networks, district heating, and power supply. These service-based layers ensure accurate representation of critical utilities, facilitating resilience planning and operational efficiency.

Together, they provide a robust foundation for managing urban systems and adapting to climate challenges.

Overall, the Pilsen NBS section emphasizes integrated urban planning through a combination of environmental, infrastructural, and accessibility data. Its layered approach supports decision-making for green infrastructure expansion, pollution control, and mobility enhancement, contributing to a more sustainable and livable urban environment.

Special focus is lying on the integration of Air quality measurements and its relation to already existing dashboards, see Figure 43.

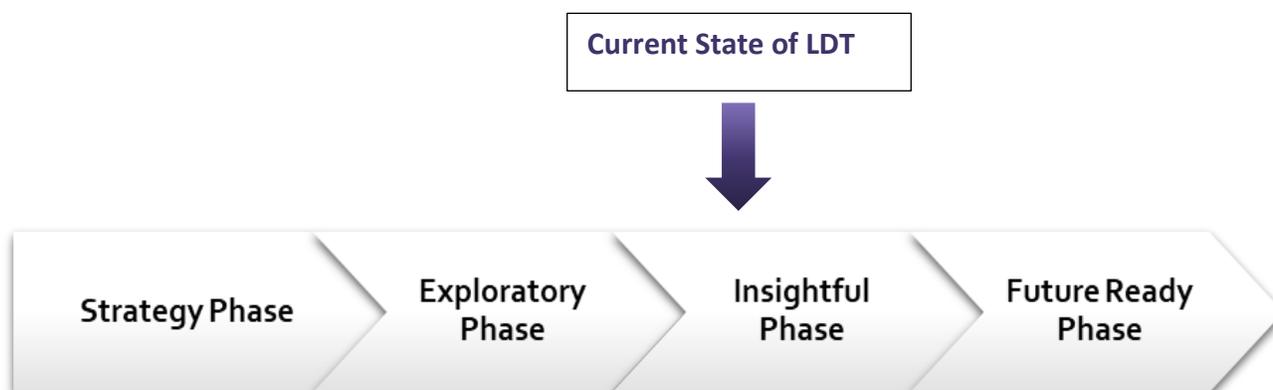
Figure 43: Air quality measurements and dashboard visualization



**Table 14: Overview of Pilsen’s NBS related datasets**

Name	Title	Format
site	NBS site	GeoJSONLayer
parks	Parks & Gardens	GeoJSONLayer
greenareas	Forest areas, natural areas, park areas	GeoJSONLayer
urban_green	Urban greenery	GeoJSONLayer
public_spaces	Public spaces with a predominance of park areas	GeoJSONLayer
forrests	Forrest	GeoJSONLayer
bigpollut	High pollution sources	GeoJSONLayer
mediumpollut	Medium pollution sources	GeoJSONLayer
airquality	Air quality measurements	GeoJSONLayer
weather	Weather stations	GeoJSONLayer
meadows	Meadows	VectorTileLayer
water	Open water bodies	VectorTileLayer
walkability_urb	15-minute city index	VectorTileLayer
wastewater	Waste water management	WMSLayer
water	Fresh water management	WMSLayer
telekom	Telecommunication management	WMSLayer
heat	District heating	WMSLayer
power	Power supply	WMSLayer

**Figure 44: Estimated current State of Pilsen’s-LDT acc. to Maturity Model**



### ***Usage of LDT***

For Pilsen, the 3D model was successfully adapted to local urban parameters, enabling its integration as a tailored tool for scenario analysis. Living Labs (LLs) actively utilized the model to simulate and compare urban environmental impacts before and after implementing Nature-Based Solutions (NBS), with participatory processes guiding scenario definition. This approach facilitated a comprehensive assessment of NBS effectiveness, allowing stakeholders to visualize and quantify changes in urban areas.

The Local Digital Twin (LDT) offers significant potential for supporting urban decision-making by integrating diverse data sources and advanced analytical tools. Through the seamless combination of 3D city models, real-time sensor data, and simulation outputs, the LDT enables stakeholders to visualize and assess the impacts of various urban planning scenarios, including the implementation of nature-based solutions (NBS). By leveraging these integrated datasets, city planners and local living labs can compare the effects of interventions before and after their adoption, facilitating evidence-based policy development and participatory processes.

Furthermore, the LDT's analytical capabilities allow for the monitoring of key urban indicators—such as energy consumption, air quality, and mobility patterns—within a unified platform. Its interoperability with IoT devices and environmental sensors ensures that the most up-to-date information is available for scenario modeling, risk assessment, and community engagement. This holistic approach supports more resilient and sustainable urban environments, tailored to the specific needs and priorities of Pilsen.

## 8 Summary of Data Availability and Modelling Challenges for LDT creation

### Summary of Data Availability

The LDTs rely on a robust, standard-compliant framework for ingesting and rendering heterogeneous urban datasets. Data is broadly categorized into:

### 8.1 Core LDT Geospatial Data

- 3D Mesh Models: Handled by 3D Tiles (OGC standard) and CesiumJS, optimized for streaming massive datasets (e.g., building models and photogrammetry).
- Elevation Data: Quantized Mesh or GeoTIFF/WMS is used to provide high-resolution terrain geometry, necessary for accurate line-of-sight and shadow analysis.
- Static Vector Data: GeoJSON (IETF standard) is used as a versatile interchange format, while VectorTile layers (like FlatGeobuf) enable efficient rendering of large-scale spatial datasets such as green areas and built environments.
- Raster Overlays: COG (Cloud Optimized GeoTIFF) layers are essential for climate data. WMS/WMTS (Web Map Service/Tile Service) provide base maps and thematic raster data, commonly used for noise mapping (Tallinn) and hydrological data (Aarhus).
- Dynamic/Real-Time Data: Data uses specialized formats like CZML (Cesium's JSON Format) for visualizing time-dynamic data and the SensorThings API standard for interconnecting IoT data (e.g., OpenAQ and Telraam sensor readings).

### 8.2 URBREATH-Generated Analytical Datasets

Datasets created by URBREATH tools are integrated into the LDTs to enable standardized analysis across frontrunner (FRC) and follower (FLC) cities:

- 3-30-300 rule/index: Available and integrated into the LDTs for Leuven, Madrid, Tallinn, and Cluj-Napoca.
- Urban Heat Islands Assessment (UHIs): Integrated into the LDTs for Leuven, Madrid, Tallinn, and Cluj-Napoca.
- Walkability / 15 min city index: Integrated into the LDTs for Leuven, Aarhus, Parma, Athens, Cluj-Napoca, and Pilsen.
- Climate Forecasts: Integrated for Leuven, Madrid, Tallinn, and Cluj-Napoca.

### 8.3 City-Owned Datasets

These datasets play a pivotal role in LDT creation, covering:

- Environmental Data: Air quality, noise pollution (Tallinn offers comprehensive noise mapping layers segmented by source and time period), vegetation, water infiltration models (Leuven), and heat wave risk (Madrid).
- Infrastructure Data: Road networks (Kajaani), underground utilities (wastewater, fresh water, power supply in Pilsen), and specific infrastructure proposals (Cluj-Napoca).

- **Data Quality:** While the goal is to use high-resolution, locally curated datasets, the necessity of having fallback datasets (e.g., from OpenStreetMap or Copernicus) is noted for continuity when city-specific data is unavailable.

## 8.4 Implied Modelling and Data Challenges

While a direct list of challenges is hard to compile several key hurdles in LDT creation can be claimed:

1. **Heterogeneity and Interoperability:** The visualization framework (VC Map) must be a hybrid web-based mapping solution combining CesiumJS (for 3D data) and OpenLayers (for 2D data). This requirement highlights the ongoing complexity of integrating datasets provided in vastly different geospatial standards, projections, and formats (e.g., WMS, WFS, GeoJSON, 3D Tiles, COG, CZML).
2. **Data Quality and Validation:** The data inventory document explicitly mentions the necessity for cities to not only publish data but also to ensure its quality, completeness, and relevance to local contexts. The need to flag datasets for improvement or validation suggests that achieving analytical-grade data quality remains an operational challenge.
3. **Data Gaps and Reliance on Fallbacks:** The use of fallback datasets is necessary to ensure continuity of analysis when city-specific data is unavailable. This lack of high-resolution, locally curated data for all necessary layers—such as specific infrastructure or detailed local climate inputs—poses a challenge for achieving the "Intelligent Twin" maturity phase. However, the use of fallback data (mostly not very fine grained or high-resolution data) could lead to misinterpretation especially when small-scale fine grained analysis data is ingested into the tools.
4. **Integration of Dynamic and Static Systems:** The LDT must seamlessly merge the static 3D built environment (LOD1-3 models) with dynamic, real-time sensor data (Telraam, OpenAQ). Managing this integration requires specialized tools like the Dynamic Layer Tool, which allows users to incorporate external data on the fly, demonstrating a complexity beyond simple static model construction.
5. **Data Dependency for Advanced Tools:** While advanced analysis tools (e.g., Ground Excavation) are universally available across all nine LDTs, their actual use and utility are dependent on the presence of specific data layers. For example, ground infrastructure analysis is only possible where the city has provided the necessary underground data.

## 9 Storytelling and Its Role in Urban Digital Twins

Based on the functionality and intended use of the Local Digital Twin (LDT) and its tools—which constitute the core of the URBREATH framework—storytelling can fundamentally aid cities in promoting their Nature-Based Solutions (NBS) activities by translating complex technical simulations into clear, comparative, and actionable narratives:

### 9.1 Creating "Before and After" Impact Narratives

The primary function of the LDT framework is to compare the simulated effects on urban areas assessed before and after the adoption of NBS measures. This core capability allows cities to construct compelling "before-and-after" narratives demonstrating tangible benefits:

- **Climate Resilience:** By using the Shadow Analysis tool, a city can visually contrast shading percentages without NBS planning versus NBS planning. This narrative highlights the significant role of NBS (like trees) in controlling shading levels and reducing heat exposure during peak sunlight hours. The tool also estimates temperature changes based on shadow coverage, providing realistic, quantifiable results for each time step.
- **Future Vision:** The Growing Trees plugin enables the city to simulate the linear growth of newly planted trees over several years. This creates a powerful predictive story by showing the baseline "now" state compared to projected future states (e.g., "in 5 years"). This story directly relates to the KPI for Increase share of NBS area covered by tree canopy (BIO-KPI7).

### 9.2 Visualizing Key Performance Indicators (KPIs) and Data

The LDT helps promote NBS activities by democratizing access to the resulting data and performance metrics:

- The results from the Growing Trees plugin can be exported in formats like visual maps of tree growth, summary tables, diagrams, and PDF reports. These easily shareable documents provide evidence-based arguments for the NBS benefits.
- The system integrates URBREATH-generated analytical datasets, such as the 3-30-300 rule and the Urban Heat Islands Assessment. Visualizing these data layers over time (especially UHI layers with a time slider) allows cities to tell a story about how NBS interventions successfully mitigate heat concentrations.
- The walkability / 15 min city index can be presented using live styling to create a clear, location-specific overview of service accessibility. This visual story promotes how NBS planning supports improved local livability and reduces car dependency, aligning with sustainable mobility goals.

### 9.3 Fostering Transparency and Participation

Storytelling is instrumental in engaging the public, aligning with the project goal of scenarios defined through participatory processes:

- The integration of city-owned datasets and simulations into the LDT viewer makes complex urban data accessible, interpretable, and actionable for a wide range of stakeholders, including citizens and policymakers.

- This democratization of data fosters transparency and encourages civic engagement, allowing communities to better understand their environment and participate in urban development processes.
- To further improve the LDT and Participation, the LDT should be able to integrate citizen and participatory data—such as geolocated feedback points—which effectively humanizes the digital twin, showing not just infrastructure and data streams, but the lived experience of the urban population. This ability to integrate community input turns the technical simulation into a co-created public narrative.

## 10 KPI Manager

The KPI Manager is the tool developed within URBREATH to support the definition, management, and monitoring of performance indicators used in the Local Digital Twins and in the evaluation of Nature-Based Solutions (NBS). Originally implemented as a SaaS solution, the tool underwent significant technical and architectural evolution to make it available as an independent deployable application. The objective is twofold: on a hand, it aims to ensure the operability of the tool in multi-city scenarios, on the other hand to make cities more autonomy, reducing their reliance on external services and enabling them to customise the application to meet local requirements.

### 10.1 KPI MANAGER: Architecture and Deployment

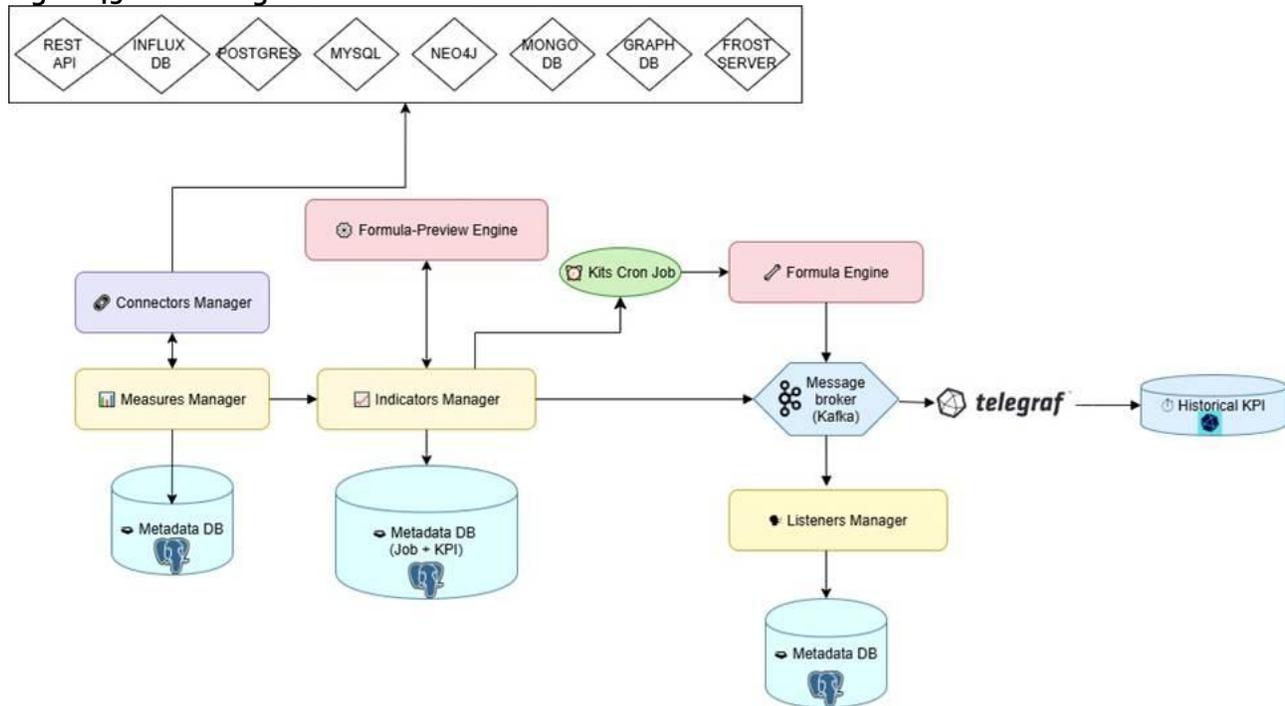
The KPI Manager is structured on a set of micro services, both for the backend and frontend-based functionalities. The main and most relevant are briefly summarised in **Errore. L'origine riferimento non è stata trovata.**.

**Table 1515: Overview of the micro services composing the KPI Manager**

Micro service	Description	Dependencies with other micro services
<b>Measure manager</b>	This microservice handles CRUD operations for the <b>Measure</b> entity, which stores connection details (URI, port, authentication, and source-specific parameters) required by the Connectors microservice to access various data sources (REST APIs, MongoDB, InfluxDB, SQL databases, etc.).	Connectors Manager, Indicators Manager
<b>Connectors manager</b>	It can handle multiple IDs provided as a comma-separated string and use them in a user-defined query to retrieve data from a data source. Depending on the data source type, the system creates the appropriate ORM-based connector. After fetching the data, it formats the results and publishes them to Kafka.	Measure Manager
<b>Indicators Manager</b>	The Indicators Manager API configures and stores KPI definitions, sets up scheduled Jobs for KPI computation, and creates Kubernetes CronJobs using the KPI Formula Engine. Results are sent through Kafka to Telegraf and stored in a Timeseries Database, enabling continuous and timely KPI updates.	Measure manager, Formula Engine, Kafka
<b>Listeners Manager</b>	The Listeners Manager API provides external systems with access to historical KPI data stored in InfluxDB. It enables querying and retrieval of past KPI measurements, ensuring seamless integration, interoperability, and data accessibility within the KPI Management system.	Kafka
<b>Formula Engine</b>	The Formula Engine microservice evaluates complex KPI formulas by orchestrating data retrieval and calculation across the KPI Management System. It extracts formula parameters from a Job, gathers measure metadata from the Measure Manager, fetches real-time values through the Connectors Manager, and retrieves	Indicators Manager, Kafka

historical KPI data from the Listeners Manager when needed. After computing the formula, it sends the result via Kafka to Telegraf for storage in the Timeseries Database, supporting continuous or scheduled KPI computation.

Figure 45: KPI Manager's architecture



Since the tool relies on functionalities commonly provided by Kubernetes<sup>3</sup> (e.g., cron job<sup>4</sup> management), Minikube was adopted as a lightweight and easily deployable solution. This allows to benefit from the key features of Kubernetes without the need for a large-scale Kubernetes infrastructure.

The reference deployment is now hosted on a dedicated URBREATH server, implementing a microservices architecture:

- Backend executed via Minikube<sup>5</sup> in a Kubernetes environment.

<sup>3</sup> Kubernetes is a portable, extensible, open source platform for managing containerized workloads and services, that facilitates both declarative configuration and automation (<https://kubernetes.io/docs/concepts/overview/>).

<sup>4</sup> A *CronJob* creates *Jobs* on a repeating schedule (<https://kubernetes.io/docs/concepts/workloads/controllers/job/>).

<sup>5</sup> Minikube is a tool that creates a single-node Kubernetes cluster on a machine.

- Frontend containerized with Docker and served through Nginx<sup>6</sup>, which provides a unified entry point for users.

This setup enables targeted updates to individual components without impacting the entire system.

## 10.2 Integration with the Authentication System

The KPI Manager is integrated with Keycloak (Ref D4.7) and connected to the realm dedicated to the project. Nine groups have been configured in Keycloak, one for each pilot. Each KPI Manager user is associated with the group corresponding to their city, allowing measurements and KPIs to be automatically linked to the specific context of the city in question.

As outlined in the architectural overview, the KPI Manager is built using a microservice architecture, with the backend and frontend components operating independently. Authentication settings, such as the realm name, client identifier and client secret, are not embedded within the microservices themselves, but are instead managed centrally through the middleware layer.

Therefore, any change to the Keycloak realm or client configuration requires the corresponding values to be updated in the middleware, which orchestrates the authentication flow across all services.

A core element of this mechanism is ETCD<sup>7</sup>, a distributed, fault-tolerant key-value store that is widely adopted in cloud-native environments for storing configuration data and service metadata. ETCD stores the dynamic configuration parameters required for the KPI Manager to authenticate against Keycloak. These include the client secret and the tenant identifier, which determine which authentication keys must be used in multi-tenant deployments. The KPI Manager can select the correct Keycloak configuration based on the tenant that invoked the service.

For a tenant named 'urbreath', for example, ETCD stores entries such as:

- URBREATH\_KPI-MANAGER-APP\_KEYCLOAK\_CLIENT\_SECRET
- URBREATH\_KPI-MANAGER-APP\_KEYCLOAK\_REALM.

This structure enables the KPI Manager to retrieve the correct authentication parameters at runtime, ensuring isolation, flexibility and scalability across different deployment environments.

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<sup>6</sup> <https://nginx.org/>

<sup>7</sup> <https://etcd.io/>

### 10.3 Localization and User Interface

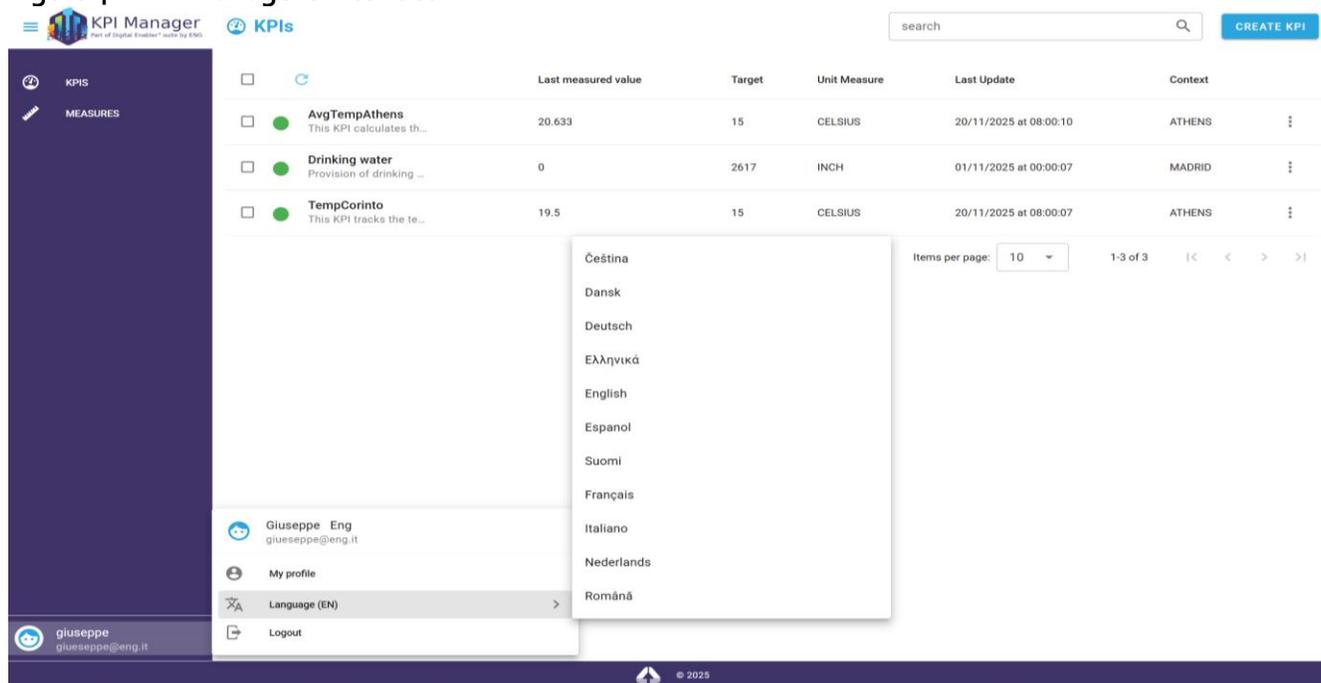
To ensure consistent usability across the different urban contexts involved in the project, the KPI Manager has been fully internationalised and localised into the languages of the pilot cities (Czech, Danish, German, Greek, English, Spanish, Finnish, French, Italian, Dutch and Romanian).

This process has been implemented directly within the front-end microservices using an extensible i18n framework.

It also allows additional languages to be introduced without altering the application logic. All textual resources, including labels, interface messages, system alerts and domain-specific terminology related to KPIs and measures, are externalised into dedicated translation files. This structure avoids hard-coded strings and ensures maintainability and consistency across modules. Language selection can be performed manually by the user via the interface.

From a design perspective, the user interface has been aligned with the URBREATH visual identity. This includes integrating the project logo, adopting the official colour palette and harmonised spacing and layout components (Figure 46). These adjustments ensure visual coherence with the other URBREATH ecosystem tools, while preserving clarity and usability. To improve the user experience, the interface also incorporates responsive design principles, enabling access from desktops, tablets, and mobile devices without compromising readability or navigation.

Figure 46: KPI manager's interface



## 10.4 KPI EXAMPLES

### 10.4.1 Indicator of Temperature Differences Across Areas

This KPI is a demonstration example that has been developed using Open-Meteo's weather APIs<sup>8</sup>. Its purpose is to illustrate how external data can be integrated and aggregated to construct useful climate indicators for monitoring purposes by comparing temperature trends in different geographical areas.

Specifically, the KPI uses three measurement points within the Athens area: North, Centre and South. The current temperature at each of these points is retrieved via an API call.

Table 16 16 reportes an example of the output from the open-meteo API. Specifically, the performed query is:

```
https://api.open-  
meteo.com/v1/forecast?latitude=37.98&longitude=23.73&current_weather=true&timezone=Europe/Athens
```

For this KPI, we store the current “**temperature**” under the field “**current\_weather**”.

**Table 16 16: Example of the output from the open-meteo API**

```
{  
  "latitude": 38,  
  "longitude": 23.75,  
  "generationtime_ms": 0.0642538070678711,  
  "utc_offset_seconds": 7200,  
  "timezone": "Europe/Athens",  
  "timezone_abbreviation": "GMT+2",  
  "elevation": 99,  
  "current_weather_units": {  
    "time": "iso8601",  
    "interval": "seconds",  
    "temperature": "°C",  
    "windspeed": "km/h",  
    "winddirection": "",  
    "is_day": "",  
    "weathercode": "wmo code"  
  },  
}
```

<sup>8</sup> <https://open-meteo.com/>

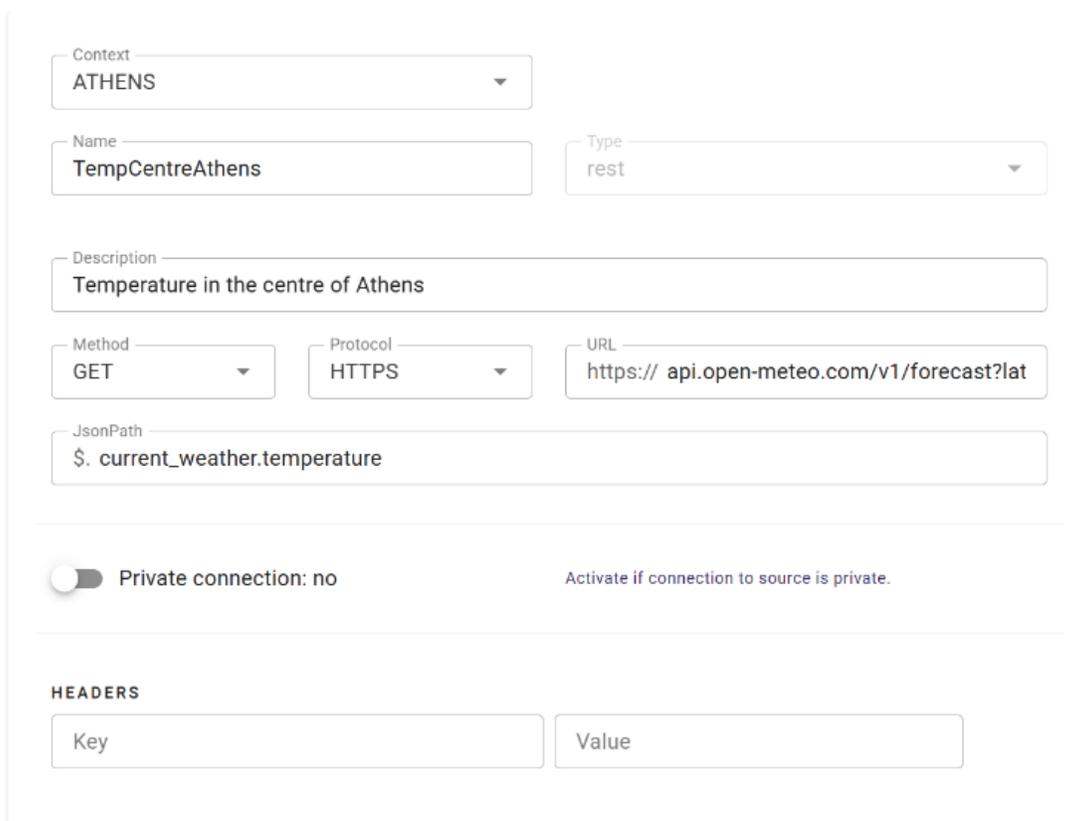
```

"current_weather": {
  "time": "2025-11-27T18:30",
  "interval": 900,
  "temperature": 17.6,
  "windspeed": 13.9,
  "winddirection": 190,
  "is_day": 0,
  "weathercode": 3
}

```

As a first step, prior to defining the KPI, the three required measures were configured and stored. For each measure, the following were specified: the name, the source type (REST), the API endpoint used (open-meteo), and the corresponding JSON path, required to identify and acquire the temperature value returned by the API response (as illustrated in the previous code snippet).

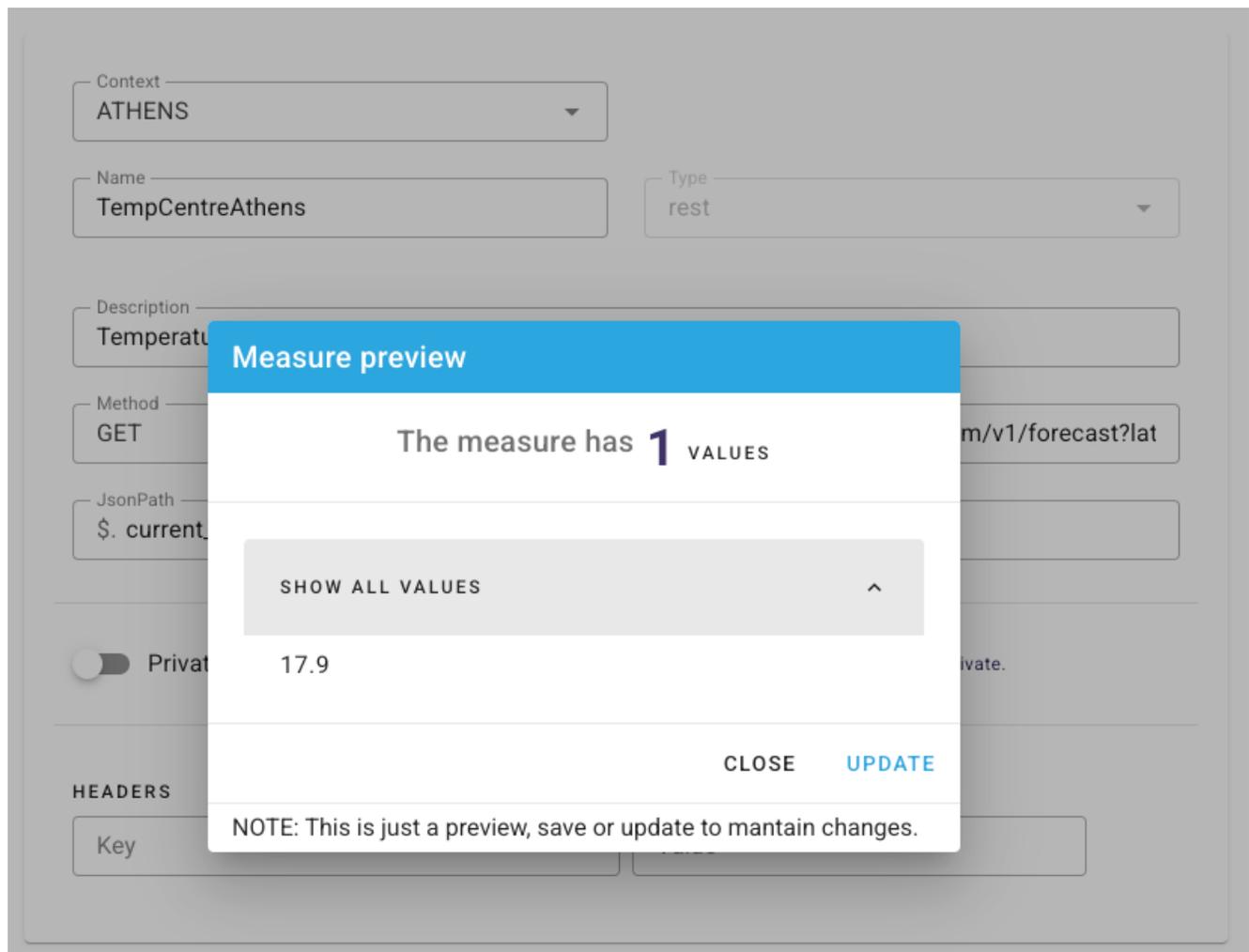
Figure 47: Measure creation



The screenshot shows a web form for creating a measure. The fields are as follows:

- Context:** ATHENS (dropdown)
- Name:** TempCentreAthens (text input)
- Type:** rest (dropdown)
- Description:** Temperature in the centre of Athens (text input)
- Method:** GET (dropdown)
- Protocol:** HTTPS (dropdown)
- URL:** https:// api.open-meteo.com/v1/forecast?lat (text input)
- JsonPath:** \$. current\_weather.temperature (text input)
- Private connection:** no (toggle switch, with note: Activate if connection to source is private.)
- HEADERS:** A table with two columns: Key and Value.

Figure 48: Measure creation – Preview of data retrieved from the configured measure



The average temperature of the Athens metropolitan area is then calculated from these three values.

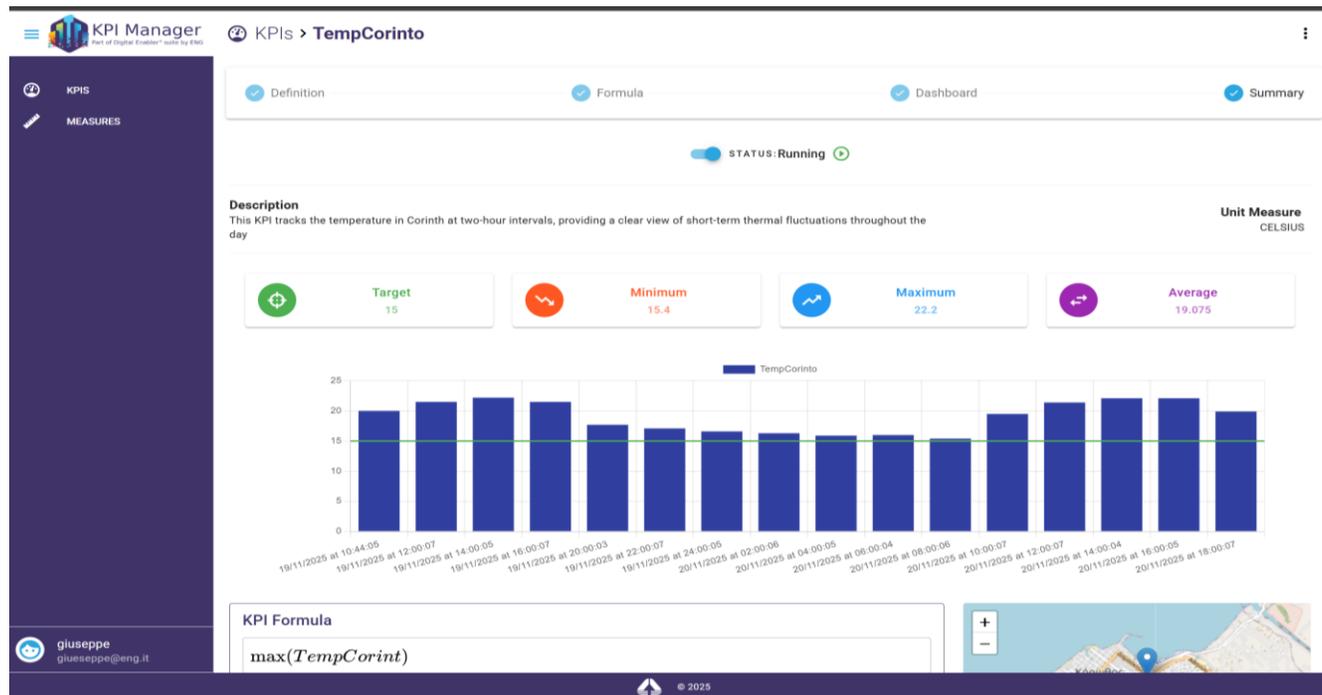
The KPI that calculates the average of the three measurements was then created. This phase defined the KPI description, the calculation formula (in this case, the average of the three acquired temperatures), the execution schedule, and the reference value (target).

Figure 49: average temperature across three areas of Athens



This aggregated data is then compared with the temperature recorded in Corinth, a more distant and geographically distinct city, to demonstrate how the tool can highlight climatic differences, deviations, or trends between different areas.

Figure 50: Temperature in Corinth at two-hour intervals



Additionally, this KPI allows for the comparison of indicators that measure the same type of metric, such as temperature in this case, highlighting differences or variations between different geographic areas.

Figure 51: Comparison of indicators



This model can easily be adapted to other datasets or types of measurement (e.g. air quality, traffic, energy consumption), demonstrating the extensibility of the KPI system.

This KPI has been implemented and contextualized for the other cities involved in the project for demonstration and training purposes, as base to get familiar with the tool.

### 10.4.2 Noise Monitoring KPIs

These KPIs offers the possibility to monitor noise pollution three areas of the city of Cluj-Napoca.

For this purpose, the KPIs leverages data collected by eight sensors distributed in three areas of the city, to produce both zone-level KPIs and an overall one. The use of multiple measurement points enables a comparative view of acoustic conditions in city areas with different urban characteristics.

Each sensor represents a measurement point located on a different street of Cluj-Napoca. sensors provide an array of noise readings (in decibel, dB), reflecting the variable sound environment throughout the day. Table 17 17 reports an example of the data provided by the sensors n Cluj-Napoca, where “noise” is the field reporting the detected noise level.

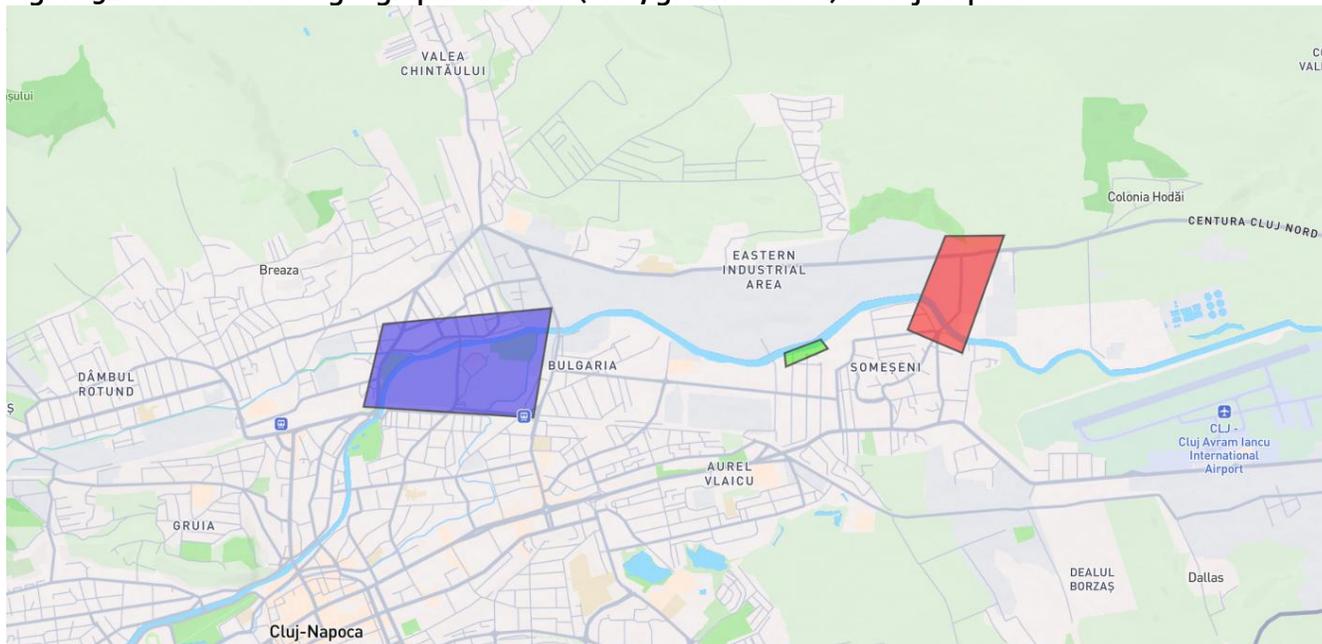
Table 17 17: Example of the output from the sensors in Cluj-Napoca

```
{
  "id": "4674",
  "time": "1764341816",
  "latitude": "46.79006800",
  "longitude": "23.64383500",
  "altitude": "390.000000",
  "temperature": "13.72000000",
  "pressure": "98019",
  "humidity": "96.49000000",
  "pm1": "15.00000000",
  "pm25": "19.00000000",
  "pm10": "21.00000000",
  "voc": "178028",
  "noise": "29.00000000",
  "co2": "441",
  "ch2o": "12.00000000",
  "o3": "20.00000000",
  "momentul_citirii": "2025-11-28 17:00:32"
}
```

As mentioned above, the streets belong to three geographical zones (Figure 52).

- East Zone (blue area) – representing an industrial and high-traffic corridor (Oasului, Barc, Bd. Muncii)
- Central Zone (green area) – representing a mixed-use central urban area (Piata 1 Mai, Timișului)
- West Zone (red area) – representing quieter residential and peripheral areas (Sahia, Blajului, Nădășel)

Figure 52: The monitored geographical zones (blue, green and red) in Cluj-Napoca



For each street, the mean value of its noise measurements is calculated. The average noise level of each zone is then obtained by aggregating the mean values of the streets belonging to that zone.

Figure 53: Average noise level calculated from sensors located on Oasului Street, Barc Street and Muncii Boulevard.

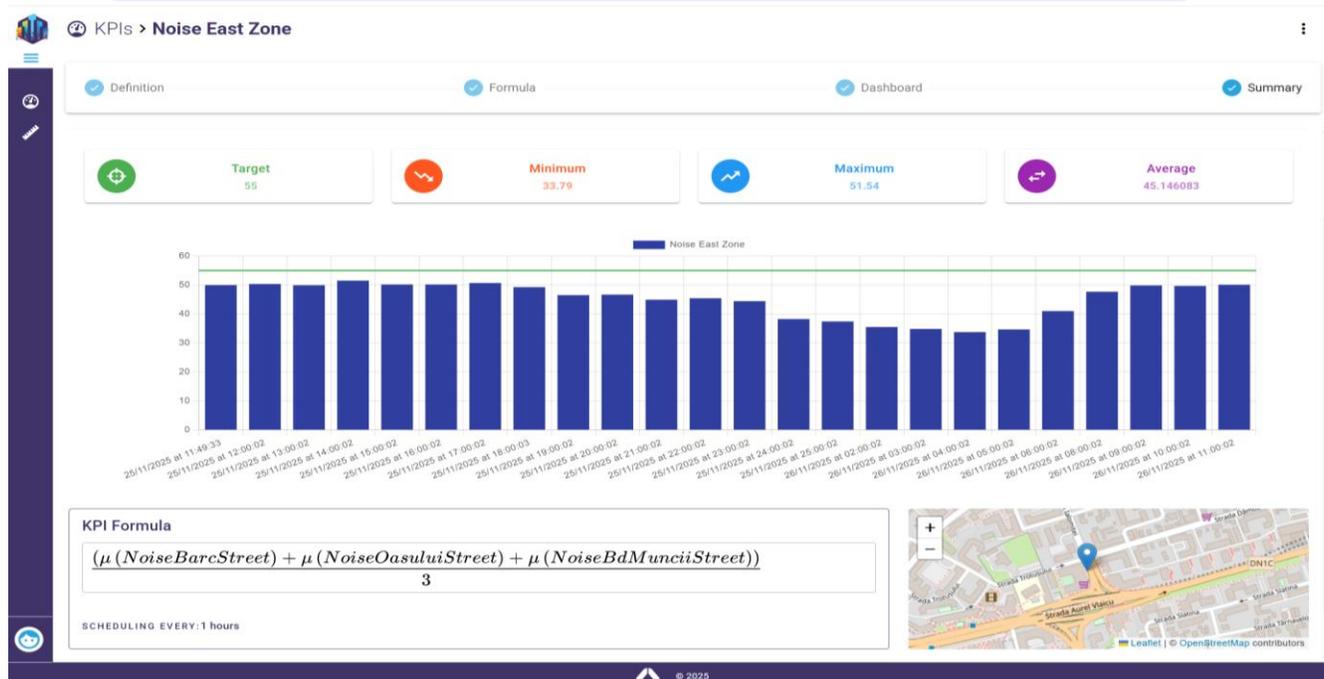


Figure 54: Average noise level calculated from sensors located on Sahia Street, Blajului Street and Nădășel Street.

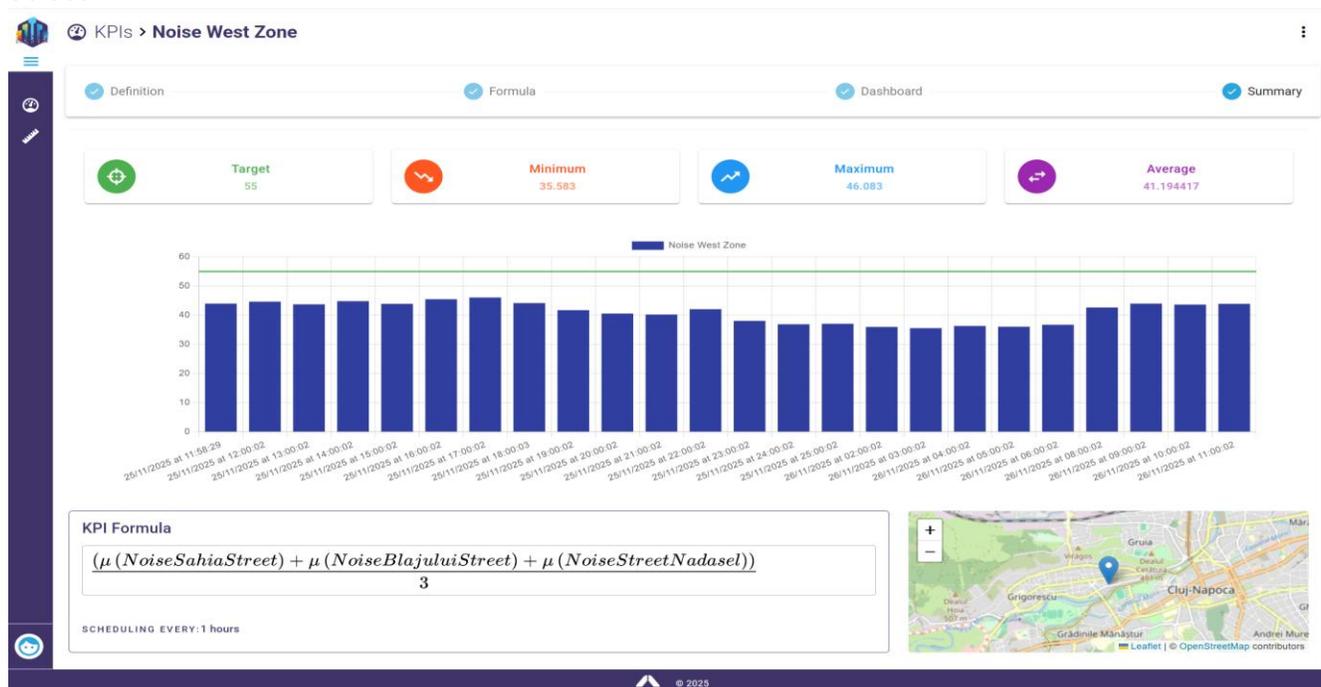
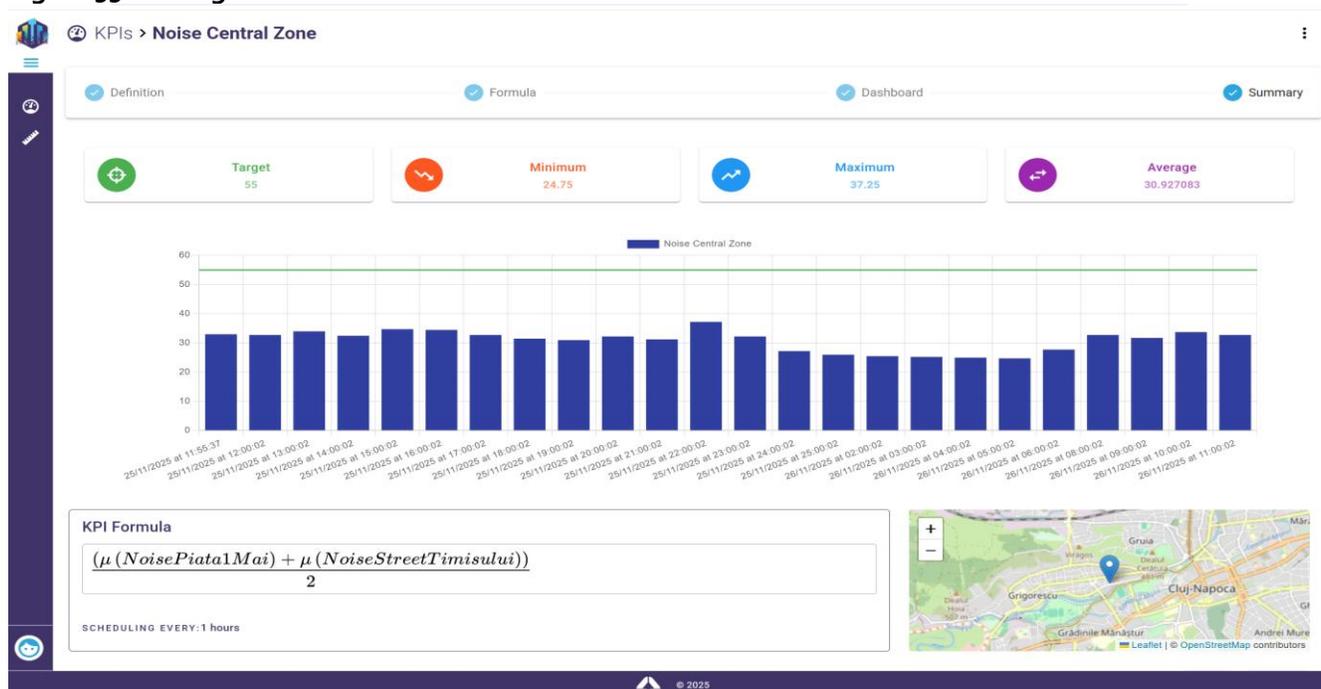


Figure 55: Average noise level calculated from sensors located in Piata 1 Mai and Timisului Street.



Finally, a global noise indicator is produced by computing the average of the three zone KPIs. This provides a single, high-level metric that represents the overall acoustic conditions across the monitored urban area.

These KPIs show how environmental monitoring data can be converted into useful information for urban planning, environmental assessment and data-driven decision-making.

## 10.5 Next steps

The current release of the KPI Manager allows to:

- define measures (the essential element to build a KPI) leveraging the possibility to retrieve data from a REST API or set of databases (such as Influx, PostgreSQL, and MongoDB);
- define a KPI through a wizard that guides the user in the selection of the measures to use and in the definition of the formula to compute the KPI, as well as in the selection of the update period and the chart type (e.g. bar, area, line, doughnut) to visualise the KPI;
- compare two KPIs.

These functionalities represent the fundamental capabilities of the KPI Manager.

The next steps consist mainly in a deeper integration with other tools of the URBREATH Toolbox, in particular, the connection with the both the FROST Server and the Orion-LD Context Broker for the publication of KPIs following the SensorThing and NGSI-LD specification, and the connection with the URBREATH Catalogue, to offer the possibility to publish KPIs as dataset (e.g. creating or updating periodically datasets offering monthly calculated KPIs).

In addition, the KPI Manager will be integrated in the e-Participation Web application as already planned in deliverable D4.1, to strengthen the evidence based participatory process.

## 11 Conclusions, Summary and Future Work

The primary goals and summary of the deliverable (D4.2) itself—which would form the basis of this concluding chapter—are documented. The deliverable is linked to Task 4.1 (T4.1) and is dedicated to the adaptation of the 3D model to every Frontrunner City (FRC). It reports on the use of this Local Digital Twin (LDT) by the Local Labs (LLs) to compare the simulated effects on urban areas. Specifically, this comparison is made for scenarios assessed before and after the adoption of Nature-Based Solution (NBS) measures in planning contexts defined through participatory processes.

The preceding chapters detail the extensive foundation (tools and data) that enable this comparative analysis. This includes specialized NBS-specific tools like Shadow analysis, Growing Trees, and Small-scale BAF calculation, alongside core URBREATH datasets such as the 3-30-300 rule/index, Urban Heat Islands Assessment, and Climate forecasts. The document also comprehensively details the implementation and maturity status of the LDTs for multiple FRCs and FLCFLCs according to the DUET Digital Twin Maturity Model.

## 12 References

- D4.1 - Local Digital Twin and KPIs catalogue for urban NBSs - V1
- D4.7 - URBREATH NBS ICT integrated solution, June 2025
- D5.1 - Local baseline state and URBREATH revisited requirements and technical framework - V1, June 2025