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

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

Project Reference No	URBREATH – 101139711
Deliverable	D4.1 Local Digital Twin and KPIs catalogue for urban NBSs - V1
Work package	WP4: URBREATH decision making framework
Type	OTHER
Dissemination Level	PU - Public (fully open)
Date	18/12/2024
Status	Final version
Editor(s)	Thomas Adolphi (VCS)
Contributor(s)	TAL, ICCS, VITO, VLO, ENG, DEDA, ATC, LAT, EXUS, TEL, FIC
Reviewer(s)	Giovanni Giacco (LAT), Maria Spanou (TEL)
Document description	Review and selection of available geospatial data for creating the Digital Twin models and development of 3D digital twin model for the FR cities. This deliverable is linked to T4.1.

Document Revision History

Version	Date	Modifications Introduced	
		Modification Reason	Modified by
V0.1	15/07/2024	TOC	VCS
V0.2	18/10/2024	KPI	VCS
V0.3	08/11/2024	KPI / LDT	VCS
V0.4	15/11/2024	Story telling	VCS
V0.5	21/11/2024	LDT levels and maturity	VCS
V0.6	28/11/2024	KPI Manager	ENG
V1.0	29/11/2024	Review ready	VCS
V1.1	11/12/2024	Review	R1 (LAT)
V1.1	05/12/2024	Review	R2 (TEL)
V2.0	12/12/2024	Post review finish / Submission ready	VCS
V2.1	16/12/2024	Submitted to Project Coordinator for quality check	VCS
V2.2	18/12/2024	Final version ready for submission	LC

Disclaimer

Executive Summary

The document *D4.1* outlines the development of Local Digital Twins (LDTs) for European cities within the framework of the Horizon Europe project URBREATH. It details the software used (VC Publisher and VC Map), data collection and integration processes, as well as the development of a Key Performance Indicator (KPI) catalog to monitor Nature-Based Solutions (NBS). The focus is on creating 3D models and their visualization, accompanied by a discussion of challenges related to data collection and quality. Additionally, the document highlights the importance of storytelling for the clear representation of LDTs and fostering citizen engagement.

It includes the review and selection of available geospatial data for creating the Digital Twin models and development of 3D digital twin models for the FR and FLW cities. This deliverable is linked to T4.1.

List of Figures

List of Tables

List of Terms and Abbreviations

Abbreviation	Definition
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
TMS	OSGeo - Tiled Map Service Specification
3D Tiles	OGC - community standard designed for streaming and rendering massive 3D geospatial content
OGC	Open Geospatial Consortium is an international organization dedicated to developing open standards for geospatial and location-based services.
LDT	Local Digital Twin
OSM	Open Street Map
LOD1	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.
LOD2	An enhanced 3D model of buildings with additional geometric details, such as roof structures and more accurate heights. It provides a better visualization for urban analysis and planning.
LOD3	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.

1 Introduction

This deliverable document is an accompanying document to the LDT-Demonstrators of Task 4.1 in WP 4 of Urbreath. It explains the software used and data for LDT creation as well as the key concepts of KPI catalogue.

1.1 Purpose and Scope

1.1.1 Local Digital Twins as Decision Support Systems

The concept of "**digital twins**" is used in the context of smart cities, with a focus on their implementation in specific cities or regions. Therefore, it can be inferred that "**local digital twins**" refer to the application of digital twins to **specific geographic areas**, such as cities, regions, or even neighborhoods.

A digital twin is a **virtual representation of a physical object or system**, connected through a bidirectional communication link. In the context of smart cities, a digital twin represents various aspects of a city, such as traffic, air quality, noise pollution, water management, and demographic data. It goes beyond a simple 3D model because it dynamically receives and processes data from the real world to simulate the current state and behavior of the physical twin in real time. This enables insights into the dynamics, current, and future state of the mirrored element and shows how they are influenced by internal and external factors.

The primary purpose of local digital twins is to serve as decision support systems for different stakeholders in the city, including city administrations, policymakers, urban planners, emergency responders, and citizens.

Local digital twins make it possible to link various urban datasets and integrate modeling algorithms. This enables a **better understanding of urban dynamics** and supports **more informed decision-making** in various areas, such as:

- **Urban Planning**: Digital twins can be used to simulate the impact of new development plans, traffic infrastructure, or green spaces on the quality of life in the city.
- **Traffic Management**: By simulating traffic flows, congestion can be identified, and measures can be taken to optimize traffic conditions.
- **Environmental Management**: Digital twins can help monitor air quality, noise pollution, and other environmental factors and develop measures to improve environmental conditions.
- **Crisis Management**: In the event of natural disasters or other crises, digital twins can be used to simulate the impact of the crisis and coordinate emergency response efforts.

The architecture of a local digital twin includes several components:

- **Data Sources**: Both dynamic data sources, such as IoT sensors that provide real-time information, and static data sources, like geographic data and municipal records.
- **Models**: Algorithms that process data and generate insights to support decision-making processes. There are process-centric models based on human expertise and data-centric models that learn from data collected through IoT infrastructures.
- **Brokers**: Software components that gather data from various sources and distribute it to different consumers. There are context brokers that manage contextual data and data brokers that make data accessible for analysis and modeling.
- **User Interfaces**: Present data and model results in a format that is understandable for different types of users.
- **Actuators**: Non-human elements that can trigger changes in the real world, such as traffic lights or autonomous vehicles.

The implementation of local digital twins presents several challenges:

- **Data Integration**: Linking different data sources with varying formats, time domains, and semantic interpretations.
- **Model Management**: Ensuring interoperability, scalability, and updating of models.
- **User Interface Design**: Developing user interfaces tailored to the needs of different user types.
- **Data Privacy and Security**: Protecting sensitive data and ensuring the integrity of the system.

Nevertheless, local digital twins offer several **advantages**:

- **Improved Decision-Making**: By providing a comprehensive and up-to-date overview of urban dynamics.
- **Enhanced Citizen Participation**: By visualizing urban data and enabling feedback. Digital twins can serve as platforms for citizen participation, promoting transparency and encouraging civic engagement.
- **Innovation**: By creating a platform for the development and testing of new technologies and solutions.
- **Simulation and scenario analysis**: "What-if" analyses and simulations can be conducted in a safe environment to evaluate the impact of policy measures before implementation.
- **Optimization and increased efficiency**: By analyzing real-time data, processes and resources can be optimized to improve efficiency and sustainability.

In conclusion, local digital twins are a **promising tool** for shaping smart and sustainable cities. However, successful implementation requires careful planning, consideration of ethical aspects, and collaboration among various stakeholders within the urban ecosystem.

1.1.1.1 What challenges are involved in building a digital twin for a smart city?

- **Data integration**: Integrating different data sources from various silos and formats is a complex task.
- **Data protection and security**: Protecting sensitive data and ensuring data security is of utmost importance.
- **Interoperability**: Interoperability between different systems and technologies is crucial for the success of the digital twin.
- **Complexity and scalability**: Cities are complex systems that require a scalable and flexible architecture.

1.1.1.2 What role does ethics play in the development and application of digital twins?

Ethical considerations are crucial in the development and use of digital twins, including:

- **Transparency**: The decision-making processes and algorithms used in the digital twin should be transparent and understandable.
- **Fairness**: The digital twin should not promote discrimination or inequality.
- **Responsible data use**: The protection of privacy and the safeguarding of citizens' data sovereignty must be ensured.

1.1.1.3 How can digital twins promote citizen engagement?

Digital twins can serve as interactive platforms for citizen engagement. They can:

- **Create transparency** about urban processes and decisions.
- **Provide citizens with the opportunity** to give feedback and submit suggestions.
- **Enable simulations and scenario analyses** for collaborative decision-making.

1.1.1.4 How is security and data protection ensured in digital twins?

Security and data protection are ensured through various measures, including:

- **Secure data infrastructure**: The digital twin should be built on a secure and reliable infrastructure.
- **Access control and authentication**: Access to sensitive data should be strictly controlled and authenticated.

- **Anonymization and pseudonymization**: Personal data should be anonymized or pseudonymized to protect privacy.

1.1.1.5 What are some specific use cases for digital twins in smart cities?

- **Traffic management**: Optimizing traffic flow, reducing congestion, and improving traffic safety.
- **Environmental monitoring**: Monitoring air quality, noise pollution, and other environmental factors.
- **Urban planning**: Simulating and evaluating different urban development scenarios.
- **Disaster preparedness**: Simulating disaster scenarios and developing emergency plans.

1.1.1.6 What does the future of digital twins in smart cities look like?

In the future, digital twins will play an increasingly important role in smart cities. They will:

- **Become more complex and comprehensive**: The integration of AI and machine learning will expand the capabilities of digital twins.
- **Be more interoperable**: Interoperability between different digital twins will improve.
- **Be central to citizen engagement**: Digital twins will become key platforms for citizen participation.

Digital twins are expected to become an integral part of smart city development, helping to make cities more efficient, sustainable, and livable.

1.2 Data – essentially needed to create an LDT

To create a local digital twin for a city, several key types of data are essentially needed:

1.2.1 Core Data Components

Geospatial Data

- High-resolution 3D models of the urban environment, including buildings, streets, parks, and other infrastructure [1][3]
- Accurate mapping data of the city layout

Real-Time Sensor Data

- Traffic flow information
- Air quality measurements
- Noise level readings [1]

Urban Systems Information

- Data on utilities like water, electricity, and waste management
- Public transportation schedules and routes

1.2.2 Additional Important Data

Demographic and Socioeconomic Data

- Population statistics
- Economic indicators

Environmental Data

- Weather patterns
- Green space distribution

Citizen Input

- Feedback and perspectives from residents [3]
- Data from participatory processes

Data Integration and Processing

To effectively create and utilize a local digital twin, cities need to:

- Gather diverse city information from multiple sources [3]
- Ensure data quality, availability, and interoperability [1]
- Create models that generate relevant insights from the collected data [3]
- Integrate various data sources and technologies [3]

It's important to note that the specific data needs may vary depending on the city's goals and the intended use cases for the digital twin. The first step for a city developing a local digital twin is to define the policy problems they want to address and identify the relevant use cases [1]. This will help determine the most critical data types to prioritize.

Additionally, cities must consider data privacy and security concerns, especially when handling personal data. As one expert noted, "When developing the digital twin, we need to define which questions we'd like to pose; personal data is not needed to know where to build green spaces."[3]

1.3 Approach for Work Package and Relation to other Work Packages and Deliverables

This deliverable establishes a foundational Local Digital Twin (LDT) by utilizing initial data sourced through VCS data searches. The data collection leverages Open Data Portals and city-specific websites, ensuring that each LDT is tailored to the available resources and information provided by local authorities. This deliverable aligns with Task 4.1 objectives, marking the starting point for more sophisticated, data-driven urban models.

As project findings progress, future iterations of the LDT will integrate insights and advancements from WP3 and WP5. These developments will enable adaptive evolution of the LDT, enhancing its capabilities to better serve urban analysis, simulation, and planning needs.

1.4 Methodology and Structure of the Deliverable

This Deliverable focuses on the development of Local Digital Twins (LDT) and the creation of a comprehensive Key Performance Indicator (KPI) catalog. The purpose of Deliverable is to provide an actionable framework for implementing and visualizing LDTs using advanced digital tools.

1.4.1 Methodology

The methodology involves the systematic design and deployment of LDTs to simulate and optimize local systems. Key stages include:

1. **Data Collection and Integration**: Relevant data is sourced, structured, and processed to form the basis of the LDT. The collected data is integrated within a cohesive digital model that simulates real-world conditions and scenarios.

2. **LDT Creation Using VC Publisher**: The LDTs are developed using VC Publisher, a dedicated technology that enables the generation of high-quality digital replicas. VC Publisher facilitates the process by providing tools for data aggregation, model building, and real-time updates, ensuring that the LDT reflects accurate, up-to-date conditions.

3. **Visualization with VC Map**: For visualization, the open-source tool VC Map is employed, enabling interactive, user-friendly representations of the LDT. VC Map provides spatial and graphical visualization capabilities that enhance stakeholder understanding and decision-making, allowing users to interact with the digital twin in a comprehensive way.

4. **KPI Catalogue Development**: A catalog of KPIs is established to measure and monitor the performance and efficiency of the LDT in real-time. KPIs are defined based on project goals and provide actionable insights that guide optimization efforts within the digital twin environment.

1.4.2 Structure of the Deliverable

The Deliverable is organized as follows:

- **Section 2: Basis** – Detailed description of the technology used for LDT creation, and visualization. This section covers the rationale behind the selection of VC Publisher and VC Map as technological tools for LDT development.
- **Section 3: FRC Madrid** – Explanation of the data used for Madrid's initial LDT.
- **Section 4: FRC Leuven** – Explanation of the data used for Madrid's initial LDT.
- **Section 5: FRC Tallinn** – Explanation of the data used for Madrid's initial LDT.
- **Section 6: FRC Cluj-Napoca** – Explanation of the data used for Madrid's initial LDT.
- **Section 7: Story telling** – Explanation of the technology used for NBS story telling.
- **Section 8: KPI Catalogue** – Explanation of the KPI development process, criteria for KPI selection, and the specific KPIs chosen for measuring and monitoring the LDTs. This section details how each KPI aligns with project objectives and enhances the digital twin's functionality.
- **Section 9: Conclusion, Summary and Future Work**– Summary of findings, reflections, and recommendations for future improvements or expansions of the LDTs and KPI catalog.

The Deliverable provides an overview of the initial work done in WP 4, WP 2.5 regarding implementing Local Digital Twins using VC Publisher and VC Map and furthermore presents insights into effective monitoring through well-defined KPIs.

2 Basics

2.1 VC Publisher

The VC Publisher is a specialized platform for creating and managing digital twins, particularly useful in generating Local Digital Twins (LDTs) for urban planning, infrastructure monitoring, and complex system simulations. It is designed to support the end-to-end workflow of digital twin development, including data integration, and continuous updates, ensuring that digital representations remain accurate and relevant to real-world counterparts.

2.1.1 Key Features of VC Publisher

1. Data Aggregation and Integration

VC Publisher brings together diverse data sources from geographic information systems (GIS) and other digital sources by converting raw data into streaming formats to be used in Cesium JS based browser applications like VC Map[1] [2] or TerriaJS[3].

> **CesiumJS** is an open-source JavaScript library that enables high-performance, 3D geospatial visualizations on the web, allowing developers to create interactive applications with real-time 3D mapping capabilities. It supports a detailed 3D globe rendering, along with 2D and 2.5D views, offering flexibility for various mapping needs. One of its core strengths is handling time-dynamic data, which is essential for applications that need real-time or historical data visualization, such as tracking vehicles or visualizing environmental changes. CesiumJS also supports a range of data formats, including KML, GeoJSON, glTF for 3D models, and 3D Tiles, simplifying integration with diverse geospatial data sources. The library's extensibility makes it compatible with other libraries and APIs, and its plugin-friendly architecture enables developers to expand its functionality as needed. Realistic 3D terrain and high-resolution global imagery layers enhance the visualizations, and custom terrain and imagery layers allow for detailed, localized applications.

This allows it to create a detailed digital environment by combining various data types like spatial, temporal, and environmental information, which are crucial for an accurate and holistic digital twin.

2. 3D Model Creation and Management

Using data inputs, VC Publisher generates 3D models that mirror physical assets, processes, or urban environments. The platform is highly customizable, allowing users to define the granularity and scope of the digital twin to suit project-specific requirements. This flexibility makes it ideal for creating LDTs, as users can model infrastructure, simulate behaviors, and assess different scenarios in a controlled digital space.

3. Integration with Visualization Tools like VC Map

VC Publisher is compatible with VC Map, an open-source visualization tool, allowing users to visually interact with the digital twin. VC Map can render data in 2D and 3D views, enabling spatial analysis and enhancing comprehension of complex relationships within the data. Through this integration, VC Publisher outputs are seamlessly visualized, supporting data-driven decisions and stakeholder engagement by presenting clear, interpretable results.

4. Scalability and Flexibility

[1] https://github.com/virtualcitySYSTEMS/map-ui

[2] https://github.com/virtualcitySYSTEMS/map-core

[3] https://github.com/TerriaJS/terriajs

Designed to handle both small-scale and large-scale projects, VC Publisher is scalable, making it suitable for LDTs at varying levels of complexity. It can be adapted for different sectors, including smart city management, utilities, transportation, and environmental monitoring, where the granularity of data and modeling requirements can vary.

5. Open Architecture and API Support

VC Publisher features open architecture, allowing for easy integration with external systems via APIs. This interoperability is crucial for projects that require compatibility with other digital platforms or custom applications, providing users with the flexibility to extend functionality and integrate with additional data sources or software.

6. User-Friendly Interface and Workflow Automation

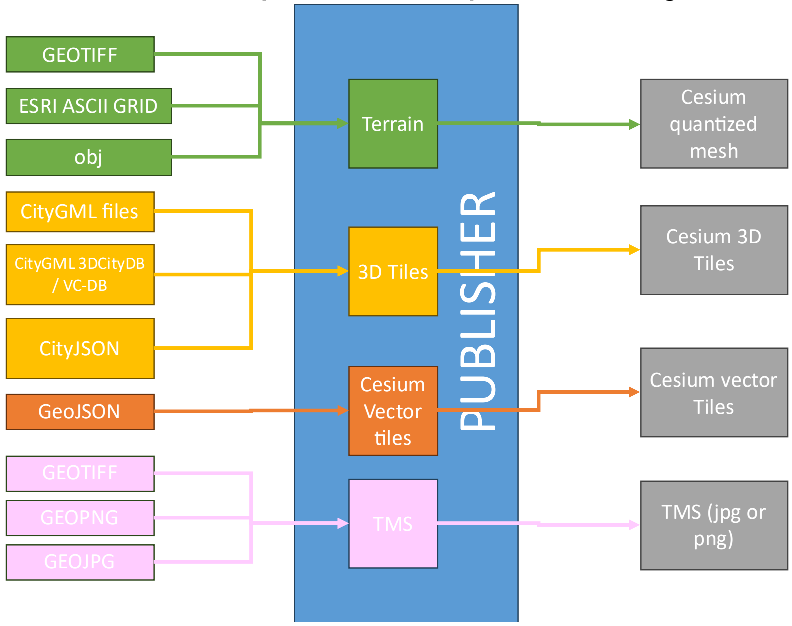
The platform is designed with a user-friendly interface that supports workflow automation, making it accessible to users with varying technical expertise. Automated data integration and model updating processes reduce the need for constant manual intervention, allowing users to focus on analysis rather than on routine data maintenance tasks.

7. Usage of VC Publisher

The VC Publisher can be used in local IT infrastructures (On-Premises) or in a hosted Cloud environment, such as AWS. This gives administrations, FRC's and FLC's the flexibility to either host the tool on their own or to make use of a full supported hosted version. Both ways highly integrate into local infrastructures and thus the tool can be used properly.

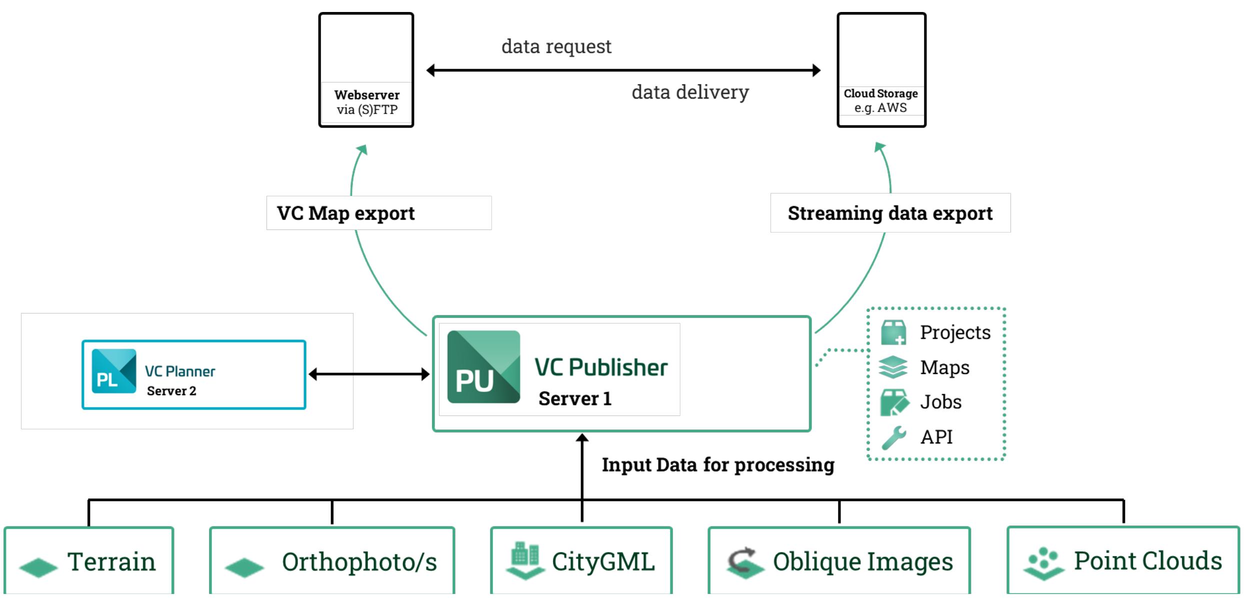
8. Data conversion capabilities

Figure 1: Data conversion input(left) and output as streaming datasets (right)



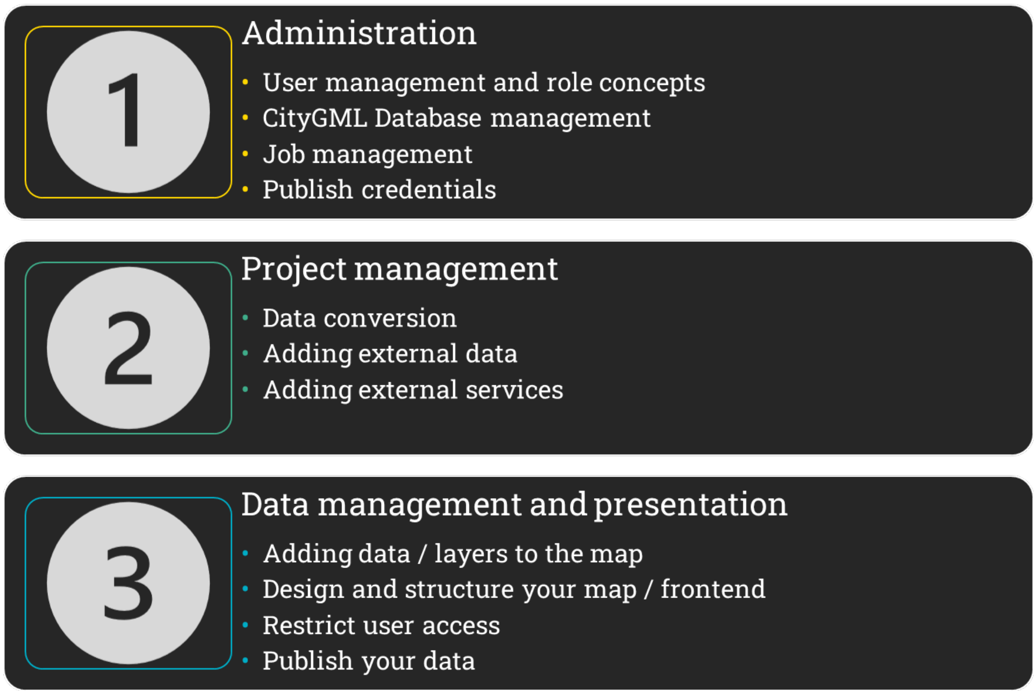
9. usual architecture scheme in local infrastructure

Figure 2: Usual architecture scheme in local infrastructure



9. 3 Levels of administration in VC Publisher

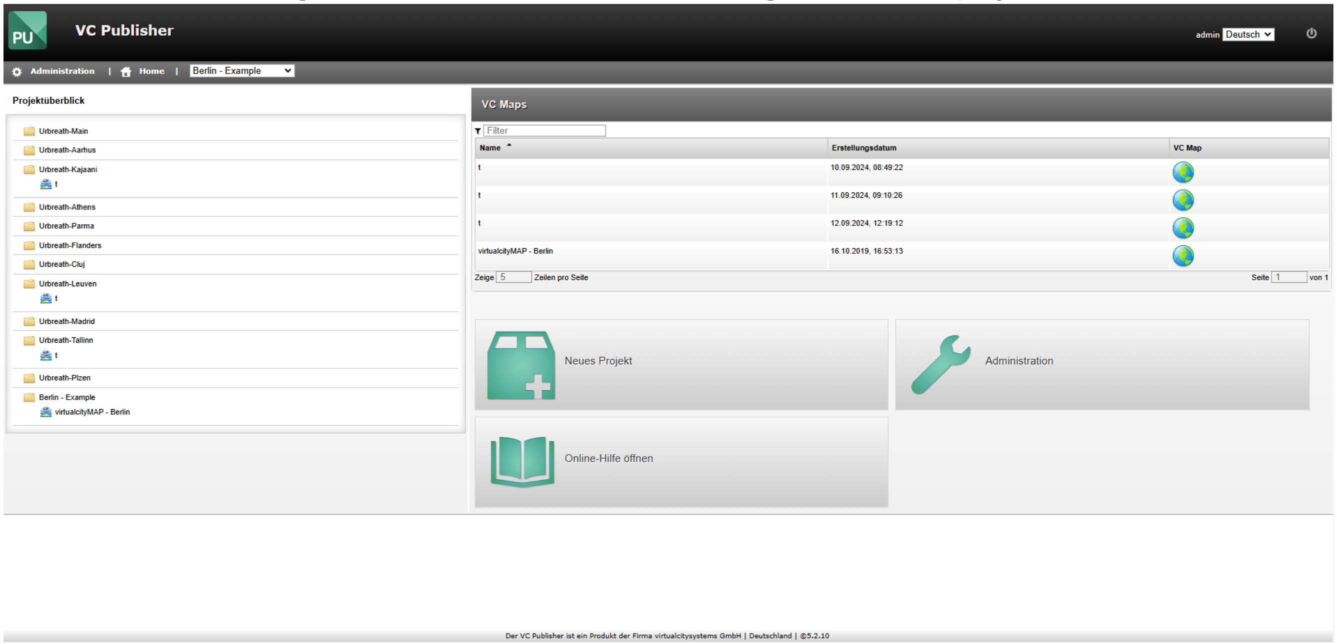
Figure 3: Administration levels in VC Publisher



In summary, VC Publisher provides a powerful toolset for creating, managing, and visualizing Local Digital Twins, offering robust functionality for data integration, model management, real-time updates, and scenario analysis.

2.1.2 Typical workflow for LDT creation using the VC Publisher

Figure 4: VC Publisher frontend showing the Urbreath projects



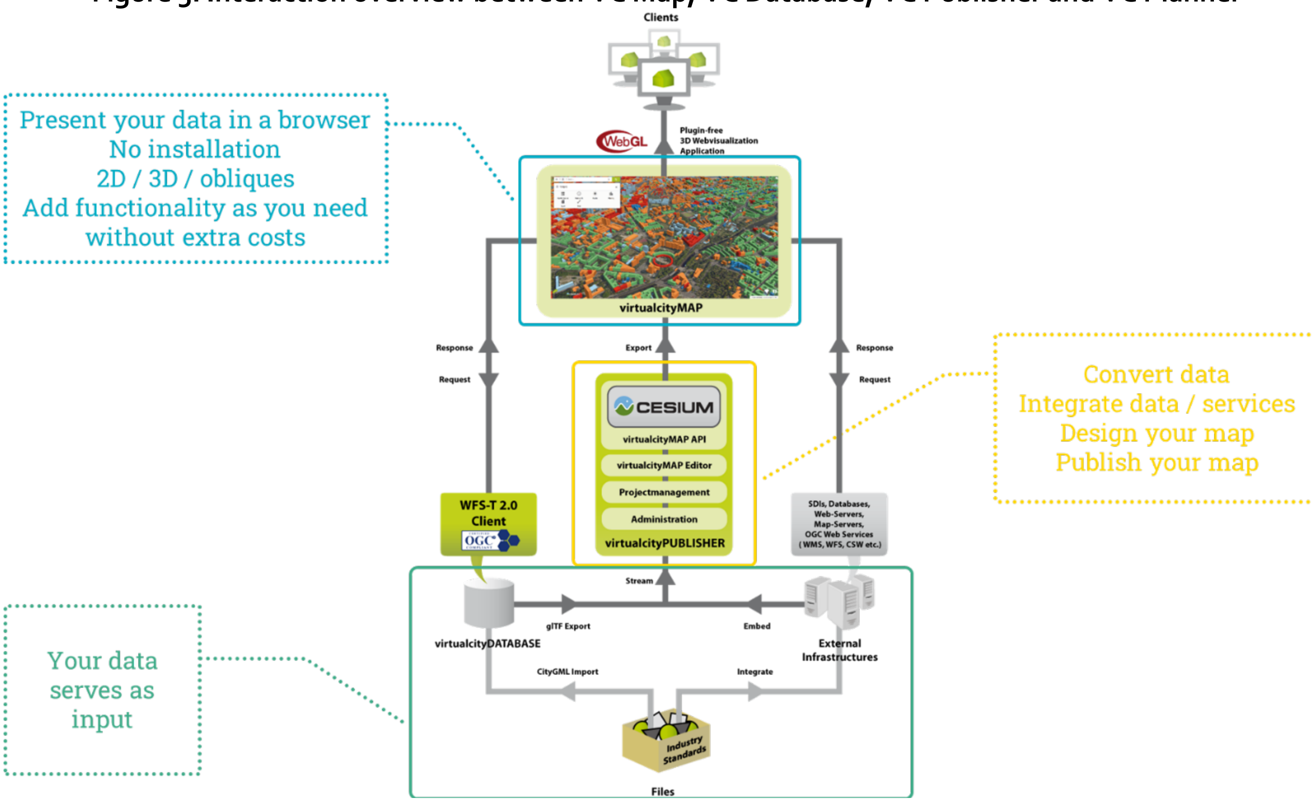
1. Collecting basic raw data for LDT (terrain data, 3d city data (CityGML, terrain overlays (ortho images, oblique images, base maps)
2. Creating a customer project in publisher
   a. User creation
   b. User role management
   c. Introducing CityGML databases and adding to specific project
   d. Adding publishing credentials
3. Converting basic raw data into streaming formats within the project
   a. Terrain data into Cesium Quantized Mesh
   b. CityGML data into Cesium 3D Tiles
   c. Ortho images, Oblique images into TMS
   d. Base maps such as city maps are taken from services (WMS, WMTS) and are introduced as datasets within a Publisher project
4. LDT creation using the converted basic data on base of VC Map
   a. Several thematic LDT's can be created within a Publisher project
5. Publishing of
   a. Streaming data and,
   b. web application

2.2 Open Source Visualization framework – VC Map

VC Map is an open-source platform designed for visualizing 2D and 3D geospatial data on the web, providing a powerful yet accessible tool for creating interactive maps and local digital twins. Built on CesiumJS, a popular JavaScript library for 3D geospatial visualization, VC Map combines the high-performance 3D rendering of CesiumJS with additional features tailored for complex data visualizations in urban planning, infrastructure management, and environmental monitoring. VC Map's architecture allows it to incorporate various map data sources, supports diverse data formats like GeoJSON, KML, and 3D Tiles, and enables users to easily switch between 2D and 3D views, enhancing the flexibility and utility of its mapping capabilities.

The dependencies of VC Map include key libraries that expand its functionality and user interactivity. **CesiumJS** is at the core, providing the 3D globe and terrain rendering needed for detailed visualization. **OpenLayer***, another widely used open-source mapping library, is also integrated, allowing for robust 2D map support and additional tools for data overlay and vector data handling. Other JavaScript libraries, such as **jQuery** for DOM manipulation and **Webpack** for bundling, help optimize the platform's performance and manage dependencies.

Figure 5: Interaction overview between VC Map, VC Database, VC Publisher and VC Planner

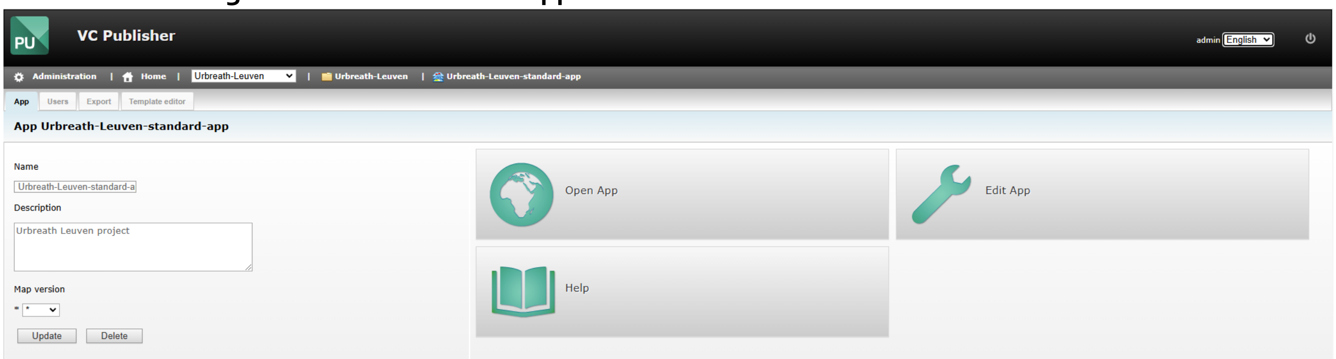


2.2.1 VC Map configuration and publishing

The VC Map in its current release v.6.0 is integrated into the VC Publisher to be able to configure and visualize the LDT before publishing it to a web server and thus making it public to the outside world.

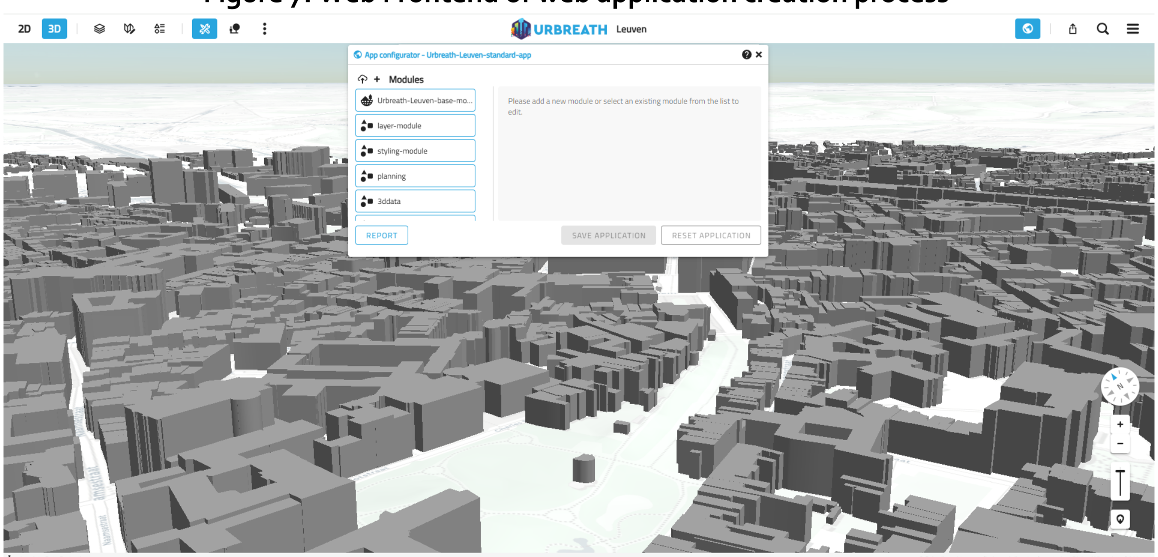
Once the raw datasets, introduced into the VC Publisher, are processed within a project and ready to be used, a visualization of the LDT can be created.

Figure 6: Creation of web application for LDT visualization in VC Publisher



As shown in Figure 6 the user can create a new web application or edit an existing web application fitting his / her needs or requirements of the LDT. A project in VC Publisher can hold unlimited web applications representing different thematic LDT's. Either on creating a new web application or in an edit scenario the user will see the view depicted in Figure 7.

Figure 7: Web Frontend of web application creation process



The view is working according to the "WYSIWIG - What you see is what you get" principle. Means whatever the user sets or defines will be directly reflected in the web front end view of the web

application.
The following can be set or adjusted:

1. Look & Feel of the web application (Design, Header, Footer, Logo, etc.)
2. Datasets to be used in web applications
3. Functionalities to be used by the user (plugins like Drawing, Measurements, etc.)
4. Content tree styling and definition
5. Legends
6. Thematic styling of data according to attributes

After adjusting the web application to user needs / requirements the created web application and its data needs to be published to a web server for hosting the web application and the datasets to a storage like Amazon s3-bucket for data hosting.

2.2.2 Basic content and functionality of each LDT

Each LDT has the same look and feel as well as the same set of base layers and functionality.

2.2.2.1 Basic content of LDT's

Basemaps

Each LDT contains a set of base layers in the section basemaps. The following layers are equal for every LDT:

1. Top Plus Open light[4] - worldwide uniform web map for use as a background map - reduced content compared to the solid TopPlus variant - representation in shades of gray and individual pale colors (borders, bodies of water)
2. Top Plus Open colored[4] - worldwide uniform web map - 19 predefined levels of detail - 3 different display areas: worldwide for small scales, Europe-wide for medium scales, detailed display for Germany and neighboring countries.
3. Very High Resolution Image Mosaic[5] - Provides at pan-European level one cloud-free very high resolution optical coverage for the 2018 reference year, provided by Copernicus

POI's

At least one POI (Point of Interest) is provided for each LDT. The basic point in general points to the geographic center of the cities bounding box.

---

4 https://mis.bkg.bund.de/trefferanzeige?docuuid=8BDFB79F-A3FD-4668-88D3-DFD957F265C2

5 https://land.copernicus.eu/api/en/products/european-image-mosaic/very-high-resolution-image-mosaic-2018-true-colour-2m

Noise maps

Each LDT contains a set of noise contour maps in the section “noise maps”. The maps are there whether data is available for the current LDT or not. The datasets are provided as WMS services by EEA (European Environment Agency)[6]. The set contains:

1. Noise roads (day & night)
2. Noise rail (day & night)
3. Noise industry (day & night)
4. Noise flight (day & night)

Environmental maps

Each LDT contains a set of environmental maps in the section “Environmental maps”. The maps are included in the LDT whether data is available or not. The datasets are provided as WMS services by EEA (European Environment Agency)[7]. The set contains:

1. Urban Atlas – Building Heights[8]: A 10m high resolution raster layer containing height information is generated for core urban areas of the EEA39 Capitals as part of the Urban atlas. Height information is based on IRS-P5 stereo images and derived datasets like the digital surface model, the digital terrain model and the normalized DSM.
2. Copernicus Land Monitoring services – Small Woody Features[9]: The Small Woody Features (SWFs) layer contains woody linear, and small patchy elements, but will not be differentiated into trees, hedges, bushes and scrub.
3. Urban Atlas – Street Tree Layer[10]: The Street Tree Layer (STL) is a separate layer from the Urban Atlas LULC Layer produced within the level 1 urban mask for each FUA. It includes contiguous rows or a patch of trees covering 500 square meters or more and with a minimum width (MMW) of 10 meter over "Artificial surfaces" (nomenclature class 1) inside FUA.
4. Urban Atlas[11]. The Urban Atlas is providing pan-European comparable land use and land cover data for 785 Functional Urban Areas (FUA). The European Urban Atlas is part of the local component of the Copernicus Land Monitoring Service (CLMS). It provides reliable, inter-comparable, high-resolution land use maps for 785 Functional Urban Area (FUA) and their surroundings (more than 50,000 inhabitants) for the reference year 2018.

---

[6] https://discomap.eea.europa.eu/Index/#/service/6717

[7] https://discomap.eea.europa.eu/Index/#/service/6717

[8] https://discomap.eea.europa.eu/Index/#/search/BuildingHeights

[9] https://discomap.eea.europa.eu/Index/#/search/HRL_SmallWoodyFeatures

[10] https://discomap.eea.europa.eu/Index/#/search/UA_StreetTreeLayer

[11] https://discomap.eea.europa.eu/Index/#/search/UA_UrbanAtlas_2018

5. Copernicus Land Monitoring services – River Network[12]: U-Hydro is a dataset for all EEA39 countries providing photo-interpreted river network, consistent of surface interpretation of water bodies (lakes and wide rivers), and a drainage model (also called Drainage Network), derived from EU-DEM, with catchments and drainage lines and nodes.

2.2.2.2 Basic functionality of LDT

Each LDT has a set of basic functionalities – in terms of VC Map called plugins. Basic functionality can be used within the LDT without any additional service / backend component.

- Switch between map representations 2D/3D
- Information Tool – accessing attributive information on 2D / 3D features on click
- Drawing Tool – allows drawing of features in 2D or 3D
- Shadow Analysis – allows simulation of shadows casted by 3D objects either existing ones or drawn or imported (by VC Planner) ones
- Swipe Tool - allows comparison of layers by swiping from left to right
- Camera flightd – allows the creation of fly throughs the scene by setting viewpoints and playing along the defined path
- Measurement tool – allows measurements in 2D or 3D
- Viewshed analysis – allows the analysis of visibility from a viewpoint and specific direction or 360° view
- Height profile analysis - allows the analysis of heights along a line either on terrain or on top of all objects (surface heights)

2.2.2.3 Extended functionality of LDT

Each LDT has a set of extended functionalities, giving the users the ability to perform specific analysis or to integrate extended data into the LDT.

- VC Planner - The VC Planner empowers urban planners and city developers with a comprehensive suite of tools to create, analyze, and manage complex urban projects. Start by structuring project goals, phases, and milestones in a high-level overview, then leverage detailed 3D city modeling to visualize realistic urban environments. Integrate diverse spatial datasets, including GIS layers and BIM models, for a unified view that enhances data management and informed decision-making.
- Export Tool – allows the scene export from LDT and all visible objects including drawn and newly planned features into several output formats such as Shapefiles, OBJ, 3DS, STL and more
- Dynamic Layer – allows the integration of datasets coming from Web URLs or selected from metadata catalogues like IDRA-Catalogue or Piveau-Catalogue

[12] https://discomap.eea.europa.eu/Index/#/search/EUHydro_RiverNetwork

- Cyclomedia / iNovitas plugin – allows the visualization of and measurement in panorama images coming from car systems using the respective API's
- Sensor data:
    - OpenAQ- Sensors – shows data from OpenAQ and its related measurements
    - Telraam-Data – shows road segments from Telraam and its related measurements
    - Sensor-Plugin – allows the integration of sensor data from SensorThingsAPI

2.2.3 LDT levels and maturity

Why is this relevant?

Understanding LDT (Local Digital Twin) levels and maturity is essential to gauge the current state of Urbreath's LDT implementation and to monitor its evolution throughout the project. These levels provide insights into how the digital twin is being developed and its alignment with project goals.

The **Digital Twin Maturity Model** serves as a crucial framework for cities, organizations, and decision-makers. It provides a systematic approach to adopting digital twins, enabling stakeholders to fully leverage their potential for urban planning, management, and innovation. In the context of Urbreath, while the maturity model emphasizes broader adoption and strategic utility, the LDT levels specifically focus on how citizens perceive and recognize the digital twin's integration with their real-world city. This dual perspective ensures that both technical progress and societal acceptance are accounted for, fostering a balanced and impactful implementation of digital twin technology.

RMI (described in 2.2.3.1.1) and maturity level (described in 2.2.3.2) could be used during Urbreath project for describing the evolvement of each LDT and the citizen perception.

2.2.3.1 Indicators for LDT Levels and Citizen Perception

There are several indicators and measures that can assess how citizens perceive and recognize a digital twin's integration with their real-world city. These can include qualitative and quantitative methods to capture user awareness, acceptance, and engagement. Here are some examples:

Awareness and Familiarity

Survey Metrics: Proportion of citizens who are aware of the digital twin's existence and its purpose.
Digital Interaction Rates: Number of users accessing or engaging with digital twin platforms (e.g., web applications, mobile apps).
Media Mentions and Reach: Frequency and breadth of LDT-related topics covered in local news, blogs, or community events.

Usability and Accessibility

User Feedback Scores: Ratings on ease of use, clarity, and relevance of the digital twin's interface or features.

Inclusivity Metrics: Demographic breakdown of users to assess if access is equitable across age groups, socioeconomic classes, and technological literacy levels.
Perceived Realism and Accuracy
Perception Surveys: Citizen responses on how accurately the LDT reflects their city's real-world conditions.
Comparative Error Analysis: Citizen-reported discrepancies between the digital twin and physical city elements (e.g., map inaccuracies, outdated visuals).

Trust and Credibility

Trust Index Surveys: Measuring the extent to which citizens trust the data presented in the LDT to make informed decisions about their city.
Engagement in Policy Discussions: Number of citizens who use insights from the LDT to participate in city planning discussions or provide feedback.
Engagement and Interaction
Platform Activity: Metrics such as time spent on the platform, specific features utilized, and recurring users.
Community Events Participation: Attendance and feedback from workshops or forums where the LDT is showcased.

Impact on Citizen Behavior

Behavioral Indicators: Changes in how citizens interact with city infrastructure or services based on LDT insights (e.g., traffic patterns, public transport use).
Adoption of Features: Usage rates of LDT-enabled applications like real-time air quality monitoring, traffic updates, or virtual city tours.

Citizen Satisfaction

Net Promoter Score (NPS): Measures how likely citizens are to recommend the LDT as a useful tool.
Public Sentiment Analysis: Social media and feedback analysis to gauge general sentiment toward the digital twin.

Educational and Informational Impact

Knowledge Gains: Surveys assessing whether citizens feel more informed about city planning or local developments through the LDT.
Integration into Education: Number of local schools or institutions incorporating the LDT into their curriculum or research.

By applying these indicators, cities and organizations can systematically evaluate how well the LDT resonates with their communities, ensuring its development aligns with both technical objectives and public expectations.

2.2.3.1.1 Recognition Match Index (RMI)

The **Recognition Match Index (RMI)** could quantify the perceived match between the digital twin and the real-world city based on user recognition and feedback.
Formula:

$$RMI = \frac{Number\ of\ Recognitions}{Total\ Responses}$$

- **Number of Recognitions** refers to the number of users who correctly identify the 3D digital model as their city.
- **Total Responses** include all survey participants (whether they recognize it or not).

Scoring Range:

- **0:** No recognition at all (users cannot identify the model as their city).
- **1:** Perfect recognition (all users identify the model as their city).

Data Collection Methods for RMI

Direct User Testing

- **Task:** Show participants the 3D model and ask, "Does this represent your city?"
- Responses: "Yes" (Recognized), "No" (Not Recognized), "Not Sure."
- Scoring: "Yes" counts as recognition.

Comparative Visual Testing

- **Task:** Provide users with images/screenshots of the real city alongside the 3D model and ask if they match.
- Metrics:
  - Match Rate (percentage of users identifying the 3D model as their city).
  - Confidence Levels (e.g., "How confident are you that this represents your city? Scale 1–5").

Immersive Testing (VR/AR)

- **Task:** Let users navigate the 3D environment in VR/AR and rate how familiar or accurate it feels compared to their real city.
- Include follow-up questions like:
  - "Which parts of the model feel most familiar?"
  - "Are there areas that feel inaccurate or missing?"

Extended Metrics for RMI

To enrich the RMI score, consider additional dimensions:

Familiarity Rating (FR): *Ask participants to rate the familiarity of the model on a scale (e.g., 1–5).*

- *Aggregate the scores to calculate an average familiarity score.*
- *Example: "How closely does this model reflect the real-world city?"*
- *Combine familiarity ratings with recognition data for a composite score.*

Context-Specific Identification (CSI): *Break the city into zones or landmarks and test recognition for specific areas (e.g., central park, iconic buildings).*

- *The percentage of landmarks correctly identified by users.*

Realism Perception Score (RPS): *Ask users to evaluate the model's overall realism using statements like:*

- *"The 3D model looks like my city in terms of structure and layout." (Rate 1–5).*
- *Aggregate scores for an overall perception rating.*

Mismatch Reports: *Track areas where users frequently report mismatches or dissimilarities.*

Composite Recognition Index (CRI)

A more comprehensive measure could combine the above dimensions into a single weighted score:

$$CRI = w_1(RMI) + w_2(FR) + w_3(CSI) + w_4(RPS)$$

$$Where\ w_1, w_2, w_3, w_4\ are\ weigts\ reflecting\ the\ importance\ of\ each\ dimension.$$

Example Use Case

Imagine a digital twin of City X is tested with 100 citizens:

- 80 correctly identify it as their city.
- Familiarity ratings average 4.2/5.
- 70% of landmarks are correctly recognized.

Using these metrics:

- **RMI:** $\frac{80}{100} = 0.8$
- **FR:** Average score = 4.2/5.
- **CSI:** 70%.
- **RPS:** Average realism score = 4.0/5.

These scores can be reported individually or combined into a composite score, providing a clear measure of how well the digital model matches the city's perception.

For further information, have a look at [10], [11], [12].

The idea of using perception scores or indices (such as RMI or CRI) is commonly seen in studies related to urban planning, 3D modeling, and human geography. These indices aim to quantify how closely a digital model aligns with real-world observations, often relying on participant feedback, visual recognition, and spatial familiarity. In the field of urban studies and 3D modeling, commonly used measures of spatial perception include metrics like "sense of presence," "visual realism," and "landmark recognition," which help quantify user engagement with and recognition of digital twins or 3D models. However, specific formulas and indexes like RMI or CRI are not standard in the literature; they were proposed as potential starting points for measurement, based on the concept of spatial recognition and user feedback.

2.2.3.2 *Digital Twin Maturity Model*

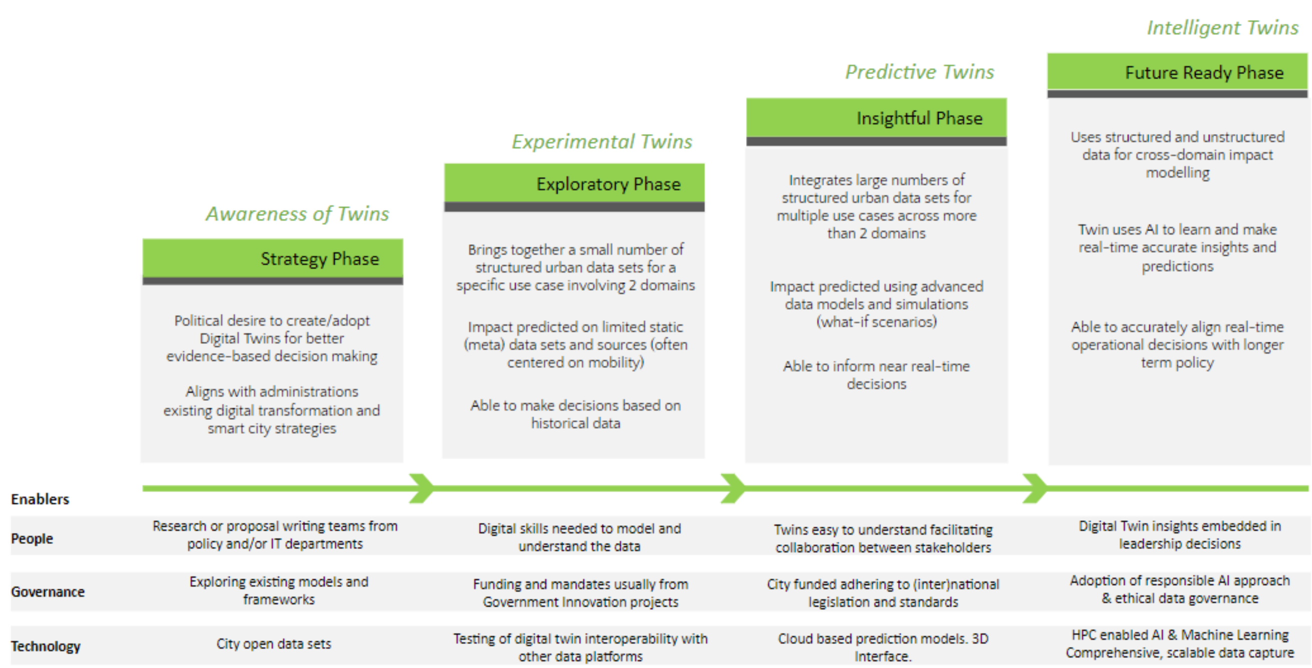
The **Digital Twin Maturity Model** from DUET is a framework designed to guide cities and organizations in developing and implementing digital twins. Digital twins are virtual representations of real-world systems, processes, or environments that help in analyzing, simulating, and improving decision-making. 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 8: Duet - Digital Twin Maturity Model



3 FRC – Madrid

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/madrid/

Collection of geospatial data

Figure 9: Overview of specific datasets for Madrid

	Data	Comments	Data	Description	Metadata
City: Madrid	*Open data root*		*https://datos.madrid.es/portal/site/egob/*		
	Open data root	*Council of Madrid*	*https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/index.iam*		
	3D Buildings	Added from the SHP3D extruded to LoD1: 3D models are only available in .OBJ or .FBX	https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/dataset.iam?id=ece2d15a-d16f-46e8-aaec-9576771b9997		https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/xml?id=ece2d15a-d16f-46e8-aaec-9576771b9997
	Orthophoto	WMS added	https://georaster.madrid.es/ApolloCatalogWMSpublic/service.svc/get?service=WMS&version=1.3.0&REQUEST=GetCapabilities&layers=ORTO_2023_10_90	https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/dataset.iam?id=cc3e4ec0-e78b-4a62-87f2-49685f71f78c	https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/xml?id=cc3e4ec0-e78b-4a62-87f2-49685f71f78c
	Heat map	WMS added	https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/dataset.iam?id=3ffba0d0-5ba2-4051-8a52-954b8b540207	https://georaster.madrid.es/ApolloCatalogWMSpublic/service.svc/get?service=WMS&version=1.3.0&REQUEST=GetCapabilities&layers=EsAytMadridOt2022ICU	https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/xml?id=3ffba0d0-5ba2-4051-8a52-954b8b540207
	Terrain 2019	Processed for the Villaverde neighborhood	https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/dataset.iam?id=8be98269-8ff1-4499-9a0a-b623a4aada8e	https://duet.virtualcitymap.de/alpha/datasource-data/05640bea-6e41-4ccd-a24e-8b4b8844938a/	https://geoportal.madrid.es/IDEAM_WBGEOPORTAL/detalle.iam?id=8be98269-8ff1-4499-9a0a-b623a4aada8e

	Data	Comments	Data	Description	Metadata
State: Communidad de Madrid	*Open data root*		*https://datos.comunidad.madrid/catalogo/*		
	Solar potential	WMS added	https://idem.madrid.org/geoidem/RecursosEnergeticos/wms?request=GetCapabilities	https://datos.comunidad.madrid/catalogo/dataset/spacm_indcfv	

	Data	Comments	Data	Description	Metadata
Country: Spain	*Open data root*		*https://datos.gob.es/es/catalogo*		

3.1.1.1 Current Status: Villaverde Digital Model

Buildings and Terrain: Processing completed exclusively for the Villaverde area.
Building Height Note: Heights are computed using $Z_{max}−Z_{min}$, which may introduce a height offset, as some buildings appear to have underground sections in the GIS data.
Trees Dataset: No available dataset for tree positions at this stage.

Figure 10: Estimated current State of Madrid-LDT acc. to Maturity Model

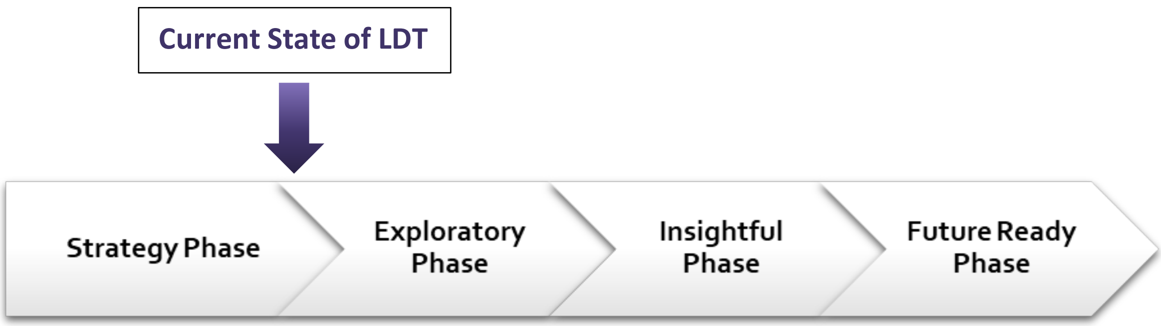
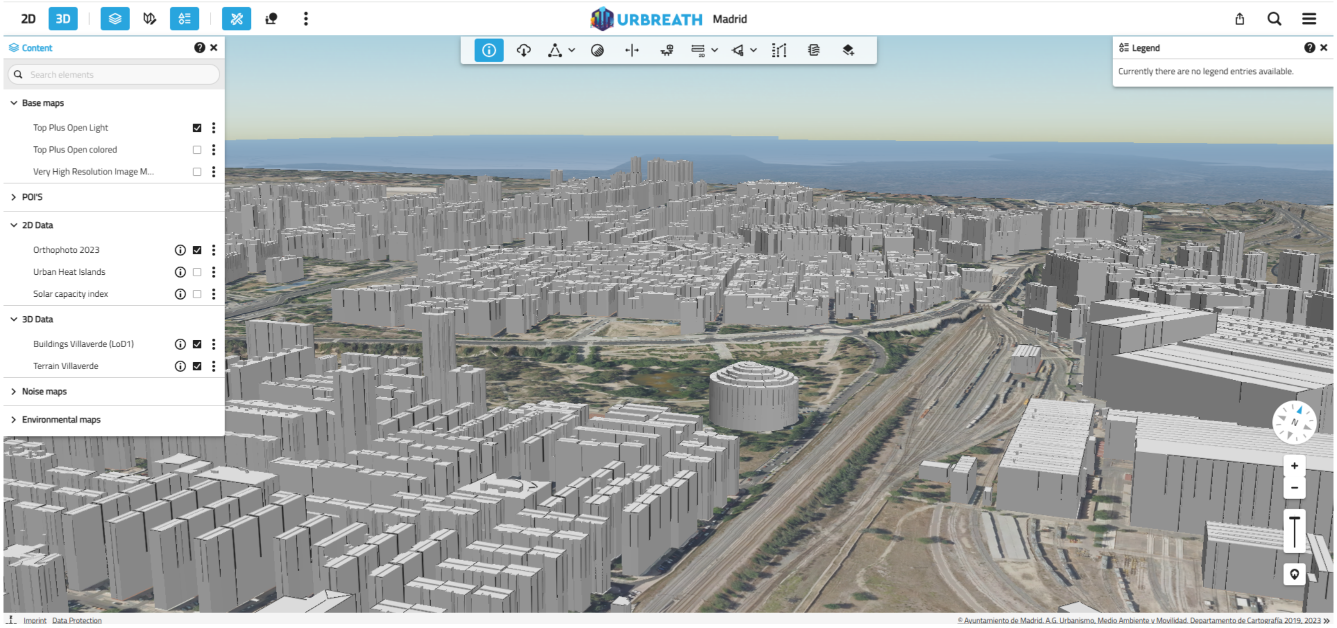


Table 1. Basic dataset availability in Madrid-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1	×	Extruded Footprints	✓
	LOD2			×
	LOD3			×
	mixed		OSM data	✓
3D surface model				×
3D terrain				✓
3D Trees				×
digital ortho photo		✓		✓
topographic map			OSM	✓

Figure 11: LDT for Villaverde District in Madrid



3.2 Follower Cities

3.2.1 Athens

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/athens/

Collection of geospatial data

Figure 12: Overview of specific datasets for Athens

	Data	Comments	Data	Description	Metadata
City: Athens	*Open data root*		*http://gis.cityofathens.gr/*		
	National Garden Trees	Restricted to 1 park and trees already added	http://gis.cityofathens.gr/layers/athens_geonode_data:geonode:dendra		
	Solar Energy Efficiency	added	http://gis.cityofathens.gr/layers/athens_geonode_data:geonode:c40solarmap	http://gis.cityofathens.gr/geoserver/wms?	*http://gis.cityofathens.gr/layers/geonode:c40solarmap/metadata_detail*
	Buildings	Buildings derived from OpenStreetMap data and extruded to LOD1 buildings by using attributes from OSM or default heights			
	Trees	Dataset provided during DUET project as tree cadastre			

	Data	Comments	Data	Description	Metadata
State: Attica	*Open data root*		https://opendata.attica.gov.gr/		

	Data	Comments	Data	Description	Metadata
Country: Greece	*Open data root*		https://geodata.gov.gr/		
	Orthophoto	Added	https://geodata.gov.gr/dataset/orthophotographies-gia-to-sunolo-tes-ellados	https://gis.ktimanet.gr/wms/wmsopen/wmsserver.aspx?service=WMS	*https://geodata.gov.gr/publicamundi/files/metadata/orthophotographies-gia-to-sunolo-tes-ellados%4007681010-4f41-43d2-8527-fefbc91101ad/download/orthophotographies-gia-to-sunolo-tes-ellados.xml*
	Aeolian map	P for the whole country, not precise enough for Athe	*https://geodata.gov.gr/dataset/aiolikos-khartes-tes-ellados*		

3.2.1.1 Current Status: Athens Digital Model

Buildings and Terrain: Processing completed but needs some better-quality data for buildings and terrain data (official city data would be helpful).

Figure 13: Estimated current State of Athens-LDT acc. to Maturity Model

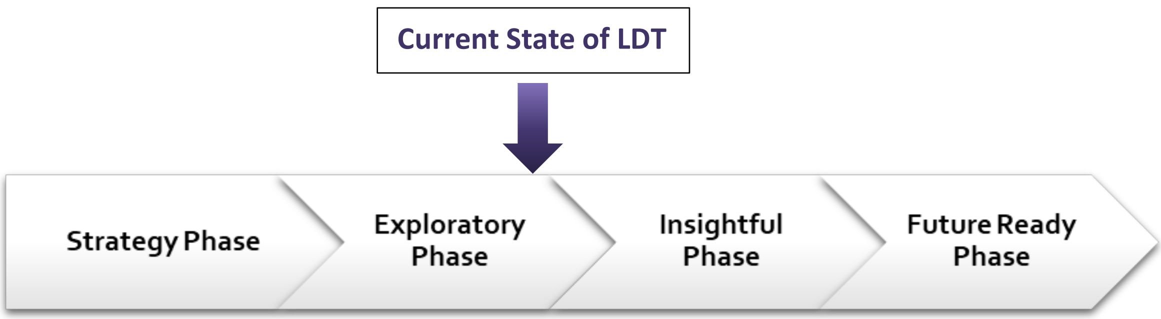
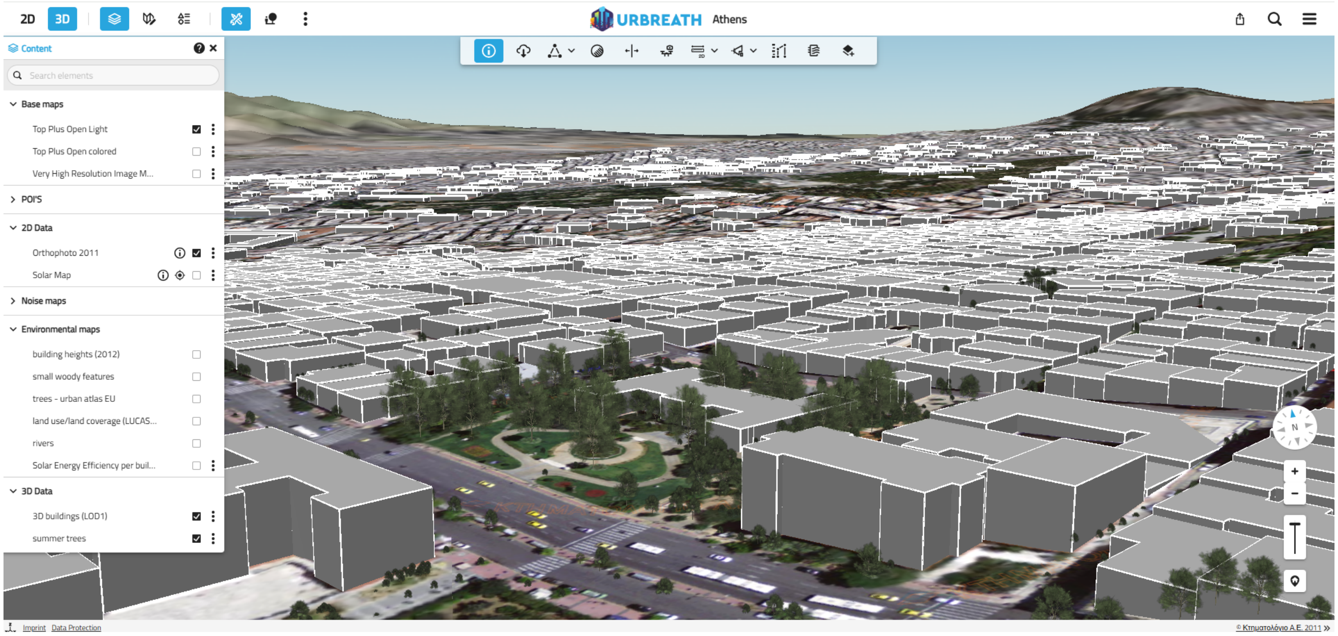


Table 2: Basic dataset availability in Athens-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1	✗	Extruded Footprints	✓
	LOD2			✗
	LOD3			✗
	mixed		OSM data	✓
3D surface model				✗
3D terrain				✓
3D Trees				✓
digital ortho photo		✓		✓
topographic map			OSM	✓

Figure 14: LDT for Athens



3.2.2 Parma

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/parma/

Collection of geospatial data

Figure 15: Overview of specific datasets for the city of Parma

	Data	Comments	Data	Description	Metadata
City: Parma	*Open data root*		*https://opendata.comune.parma.it/search/type/dataset*		
	GIS	*2D, not downloable*	*https://mappe.comune.parma.it/mokaApp/apps/STRWEB_H5/index.html*		
	Buildings footprints	Converted to LoD1	*https://opendata.comune.parma.it/dataset/livello-cartografico-dei-fabbricati-e-manufatti-di-parma-2022*	*\\fs01\vcs\00_vcs_Austausch\DEI\URBREATH_Data\Parma_BuildingsFootprints*	*https://opendata.comune.parma.it/dataset/livello-cartografico-dei-fabbricati-e-manufatti-di-parma-2022.xml?dct%3Aidentifier=78b5e39d-af72-4488-9838-556f32cd588f&page=0*
	Data	**Comments**	**Data**	**Description**	**Metadata**
State: Emilia-Romagna	*Open data root*		*https://dati.emilia-romagna.it/dataset*		
	GIS	*3D*	*https://mappe.regione.emilia-romagna.it/*		
	Terrain 5m	processed	*https://geoportale.regione.emilia-romagna.it/catalogo/dati-cartografici/altimetria/layer-2*	*\\fs01\vcs\00_vcs_Austausch\DEI\URBREATH_Data\Parma_DTM*	*https://servizigis.regione.emilia-romagna.it/ctwmetadatiRER/metadatoISO.ejb?stato_FileIdentifier=iOrg01iEnP1fileIDr_emiro:2016-08-08T155835*
	Orthophoto 2020	Check license rights	*https://geoportale.regione.emilia-romagna.it/catalogo/dati-cartografici/cartografia-di-base/immagini/layer-6*	*https://servizigis.regione.emilia-romagna.it/wms/agea2020_rgb?service=wms&request=getcapabilities&version=1.3.0*	*https://servizigis.regione.emilia-romagna.it/ctwmetadatiRER/metadatoISO.ejb?stato_FileIdentifier=iOrg01iEnP1fileIDr_emiro:2022-03-10T114950*
	Data	**Comments**	**Data**	**Description**	**Metadata**
Country: Italy	*Open data root*		*https://www.dati.gov.it/*		

3.2.2.1 Current Status: Parma Digital Model

Buildings and Terrain: Processing completed.
Trees Dataset: No available dataset for tree positions at this stage (tree cadastre).

Figure 16: Estimated current State of Parma-LDT acc to Maturity Model

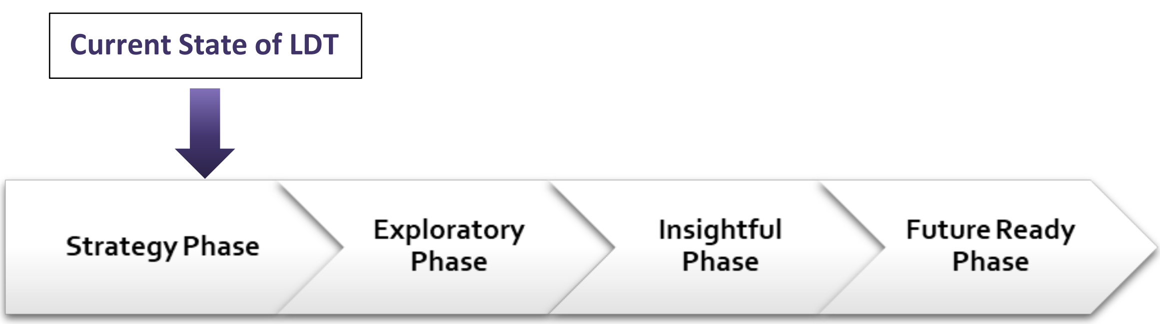
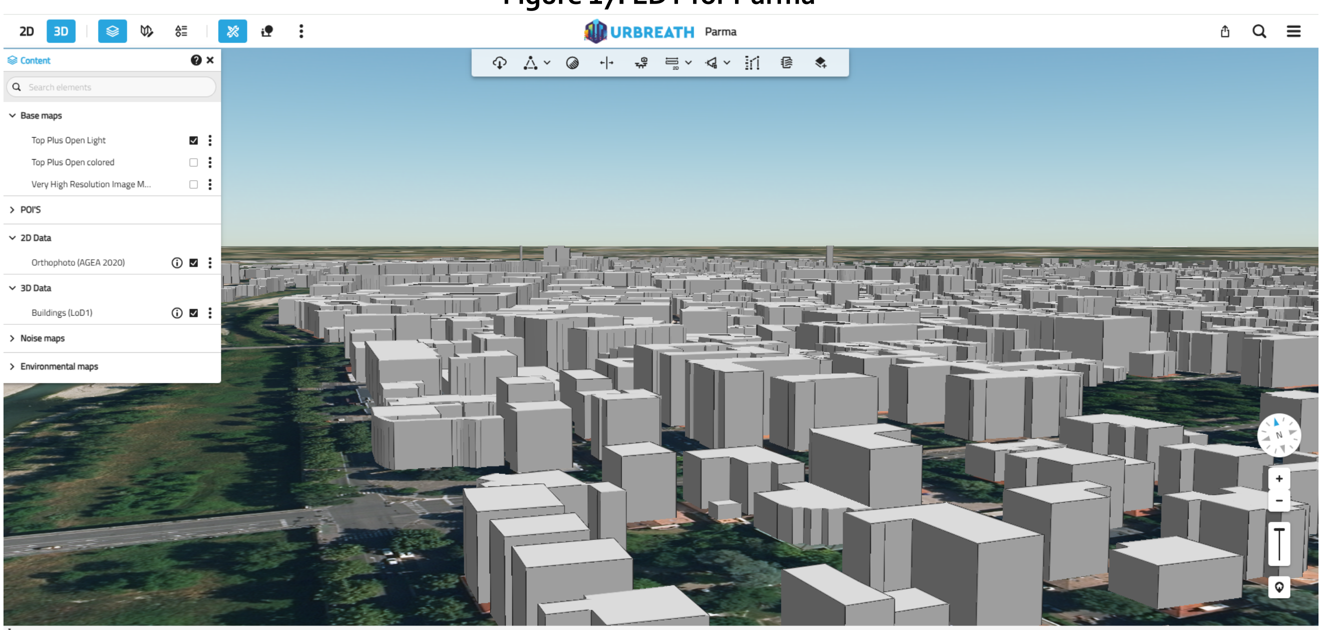


Table 3. Basic dataset availability in Parma-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1	✗	Extruded Footprints	✓
	LOD2			✗
	LOD3			✗
	mixed		OSM data	✓
3D surface model				✗
3D terrain				✗
3D Trees				✗
digital ortho photo		✓		✓
topographic map			OSM	✓

Figure 17: LDT for Parma



4 FRC – Leuven

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.

The LDT is available at. https://urbreath.virtualcitymap.de/leuven/

Collection of geospatial data

Figure 18: Overview of specific datasets for the city of Leuven

	Data	Comments	Data	Description	Metadata
City: Leuven	*root open data*				
	GIS				
State: Flanders	Data	Comments	Data	Description	Metadata
	Open data root		*https://www.vlaanderen.be/digitaal-vlaanderen/onze-oplossingen/open-data*		
	Terrain		https://download.vlaanderen.be/product/59-dhm_vlaanderen_raster_5_m		
	Lidar data (Pointcloud)		https://remotesensing.vlaanderen.be/apps/openlidar/#collapseDataDownload	https://remotesensing.vlaanderen.be/apps/openlidar/EODaS_openlidar_Handleiding.pdf	https://metadata.vlaanderen.be/srv/dut/catalog.search#/metadata/242ddabc-3cbc-44f0-9623-bee874b29549
Country: Belgium	Data	Comments	Data	Description	Metadata
	Open data root				
	Orthophoto	WMTS added	https://www.geo.be/catalog/details/29238f19-ac79-4a4a-a797-5490226381ec?l=en		

4.1.1.1 Current Status: Leuven Digital Model

Figure 19: Estimated current State of Leuven-LDT acc. to Maturity Model

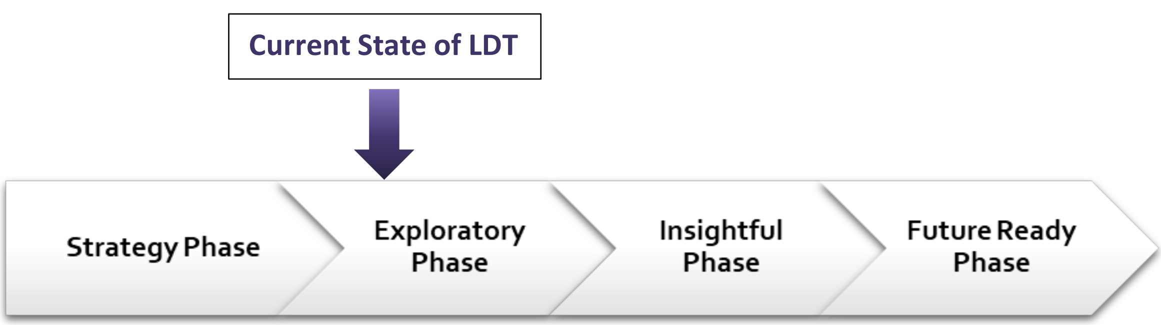
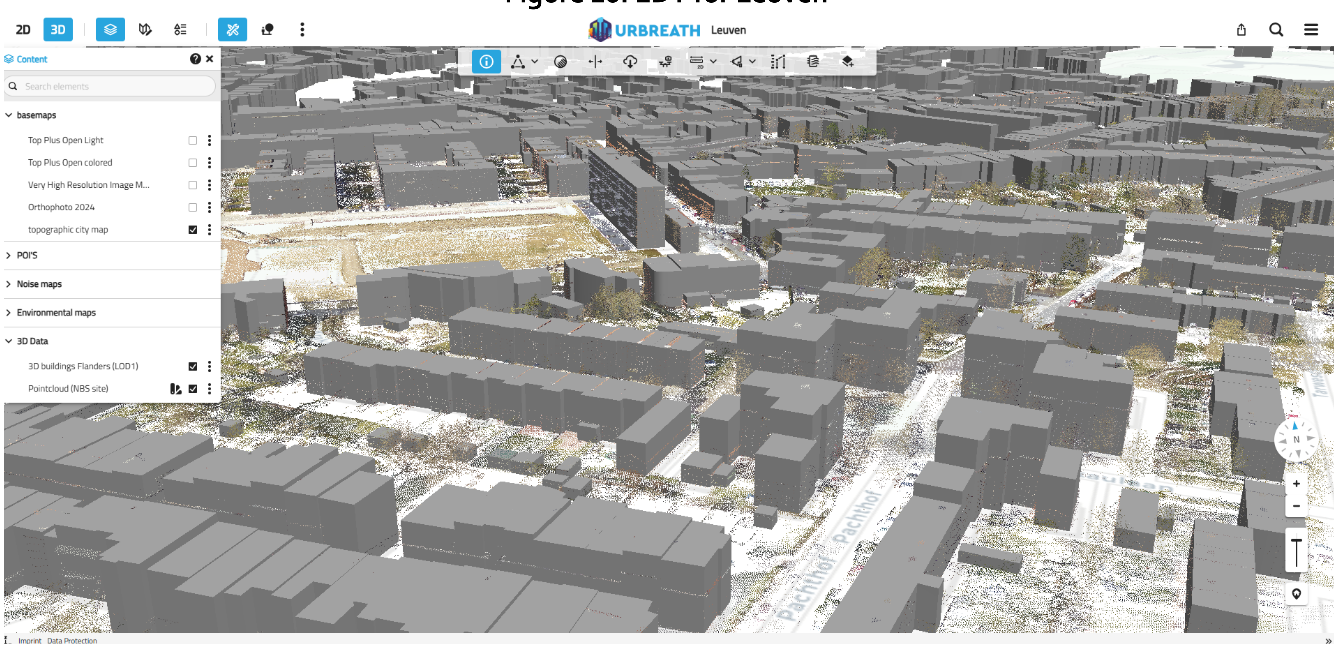


Table 4. Basic dataset availability in Leuven-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1	✗	Extruded Footprints	✓
	LOD2			✗
	LOD3			✗
	mixed		OSM data	✓
3D surface model			Point Cloud	✓
3D terrain				✓
3D Trees				✗
digital ortho photo		✓		✓
topographic map			OSM	✓

Figure 20: LDT for Leuven



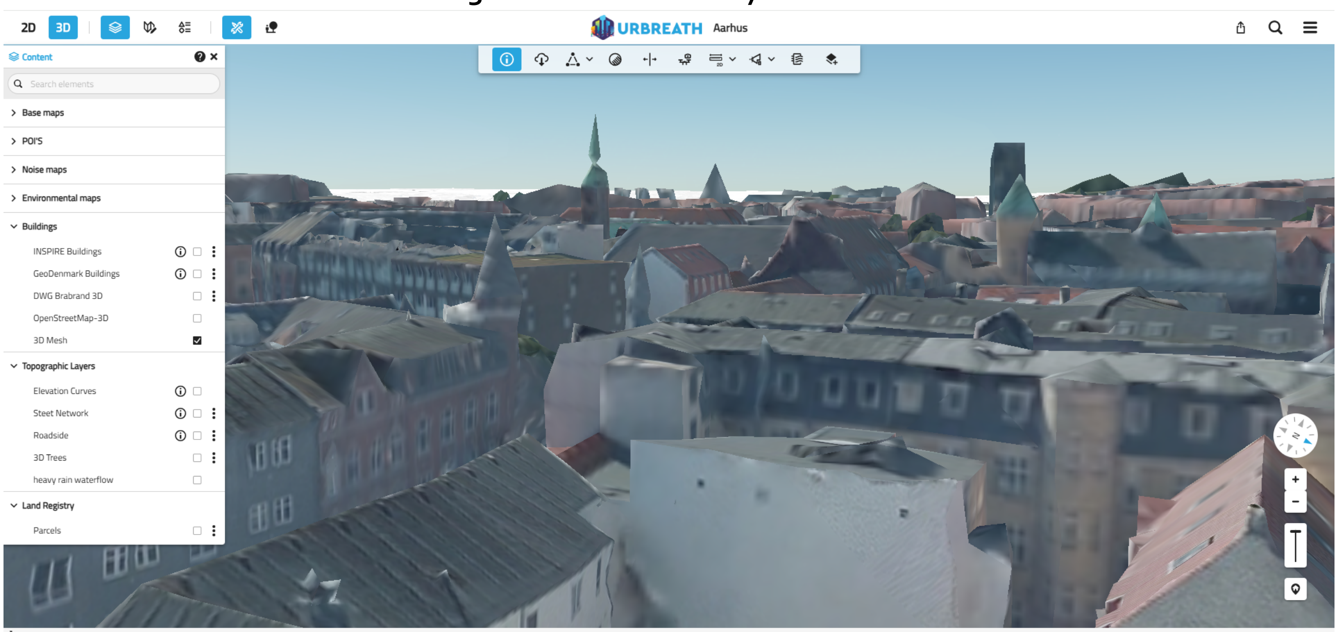
Follower City – Aarhus

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/aarhus/

Collection of geospatial data

It is worth mentioning for the city of Aarhus that, Aarhus is part of the Urbreath project, as well as the Biped project. Both projects use VCS technology for LDT representation. Thus, datasets are shared between projects, which leads in the end to a lot of datasets represented in the LDT of Aarhus.

Figure 21: LDT of the city of Aarhus



4.1.1.2 Current Status: Aarhus Digital Model

Figure 22: Estimated current State of Aarhus-LDT acc. to Maturity Model

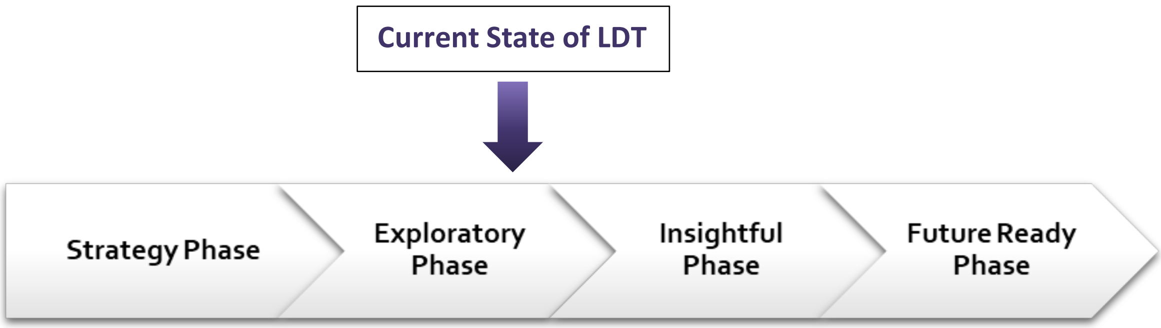


Table 5. Basic dataset availability in Aarhus-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1			✗
	LOD2	✗	CityGML	✓
	LOD3			✗
	mixed			✗
3D surface model		✓	3D Mesh	✓
3D terrain				✓
3D Trees		✓		✓
digital ortho photo		✓		✓
topographic map			OSM	✓

5 FRC – Tallinn

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/tallinn/

Collection of geospatial data

Figure 23: Overview of specific datasets for the city of Tallinn

City: Tallinn	Data	Comments	Data	Description	Metadata
	root open data				

State: Harju	Data	Comments	Data	Description	Metadata
	Open data root		*/*		

Country: Estonia	Data	Comments	Data	Description	Metadata
	Open data root		*https://geoportaal.maaamet.ee/eng/*		
	Open data root		*https://avaandmed.eesti.ee/*		
	Terrain	Already existing	*https://geoportaal.maaamet.ee/eng/Maps-and-Data/Elevation-data/Download-Elevation-Data-p664.html*		
	Orthophoto	Processed by Publisher and added	*https://geoportaal.maaamet.ee/index.php?lang_id=2&page_id=662*		
	Trees	open	*https://geoportaal.maaamet.ee/eng/spatial-data/geo3d/download-3d-data-p837.html#lod0-puud-pane*		

5.1.1.1 Current Status: Tallinn Digital Model

Figure 24: Estimated current State of Tallinn-LDT acc. to Maturity Model

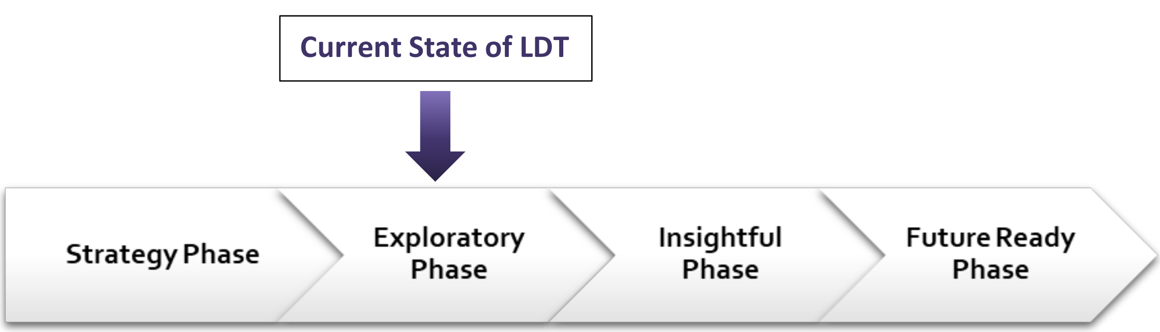
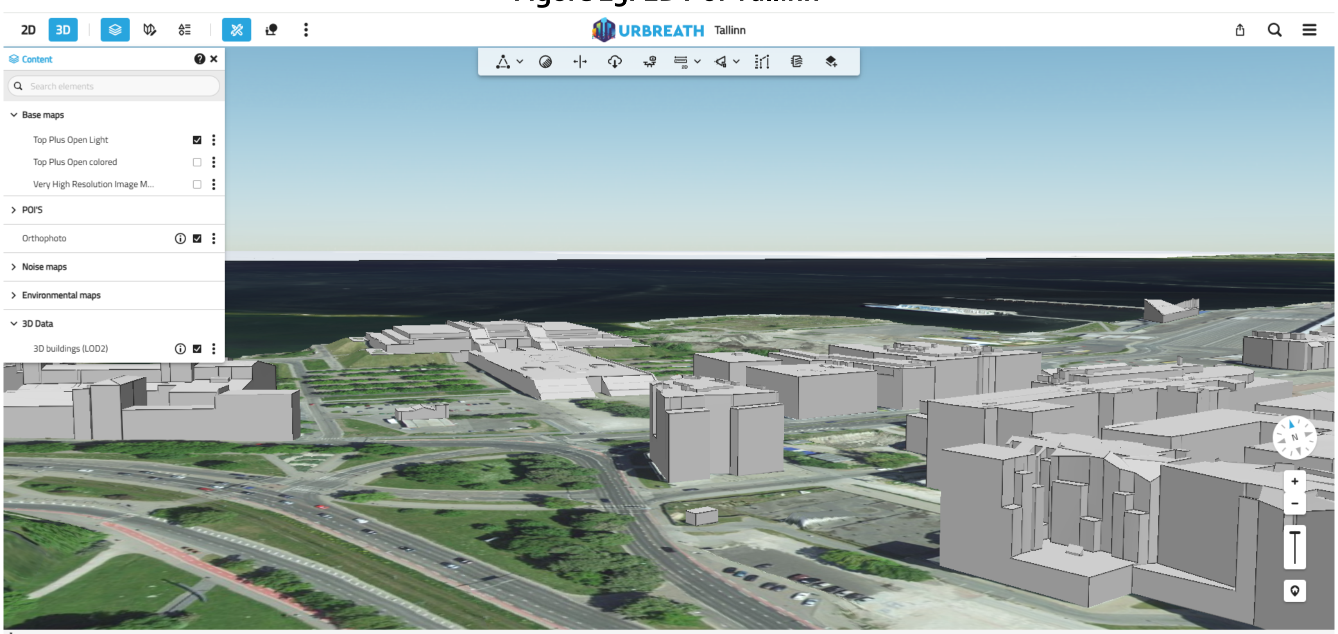


Table 6. Basic dataset availability in Tallinn-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1			✗
	LOD2	✗	CityGML	✓
	LOD3			✗
	mixed			✗
3D surface model				✗
3D terrain				✓
3D Trees				✗
digital ortho photo		✓		✓
topographic map			OSM	✓

Figure 25: LDT of Tallinn



5.2 Follower City – Kajaani

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/kajaani/

Collection of geospatial data

Figure 26: Overview of specific datasets for the city of Kajaani

	Data	Comments	Data	Description	Metadata
City: Kajaani	*root open data*		*https://www.kajaani.fi/avoin-data/*		
	WMS service	proxied by VCS, to make use of it	https://kartta.kajaani.fi/teklaogcweb/wms.ashx		
	Buildings	fixed by VCS due to some CityGML validation errors	*http://kartta.kajaani.fi/Avoin_data/3D-rakennukset_Kajaani.zip*		*R:\DEI\URBREATH_Data\Kajaani_buildings\3D-rakennukset_Kajaani_fixed.gml*

	Data	Comments	Data	Description	Metadata
State: Kainuu	*Open data root*		/		

	Data	Comments	Data	Description	Metadata
Country: Finaland	*Open data root*		*https://www.avoindata.fi/en*		
	data		*https://www.paikkatietohakemisto.fi/geonetwork/srv/fin/catalog.search#/home*		
	downloads		*https://asiointi.maanmittauslaitos.fi/karttapaikka/tilausvahvistus*		
	Orthophoto	Processed by Publisher and added	*https://www.maanmittauslaitos.fi/kartat-ja-paikkatieto/aineistot-ja-rajapinnat/tuotekuvaukset/ortokuva*		
	Terrain 2m	Processed by Publisher and added	*https://www.maanmittauslaitos.fi/kartat-ja-paikkatieto/aineistot-ja-rajapinnat/tuotekuvaukset/korkeusmalli-2-m*		
	Forest inventory	*not added*	*https://www.avoindata.fi/data/en_GB/dataset/monilahteisen-valtakunnan-metsien-inventoinnin-mvmi-kartta-aineisto-2021*		
	Soil types	*not added*	*https://www.avoindata.fi/data/en_GB/dataset/maapera-1-200-000-maalajit1*		

5.2.1.1 *Current Status: Kajaani Digital Model*

Figure 27: Estimated current State of Kajaani-LDT acc. to Maturity Model

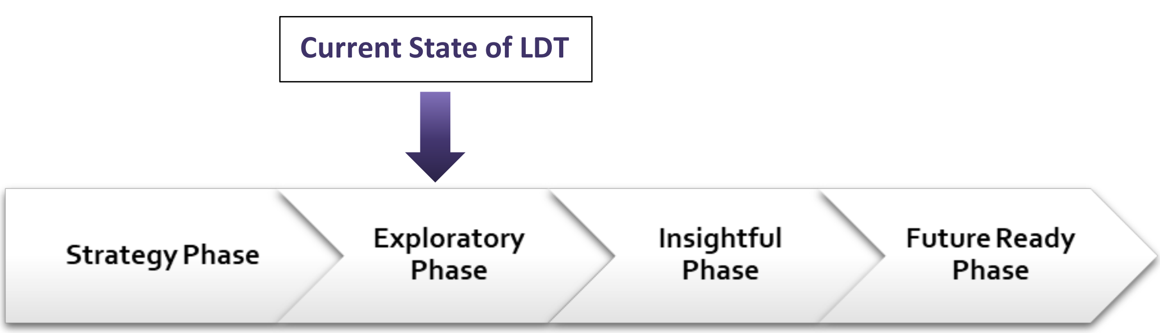


Table 7. Basic dataset availability in Kajaani-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1			✗
	LOD2	✗	CityGML	✓
	LOD3			✗
	mixed			✗
3D surface model				✗
3D terrain				✓
3D Trees				✗
digital ortho photo		✓		✓
topographic map			Various thematic City maps	✓

Figure 28: LDT of Kajaani

6 FRC - Cluj-Napoca

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/cluj/

Collection of geospatial data

Figure 29: Overview of specific datasets for the city of Cluj-Napoca

	Data	Comments	Data	Description	Metadata
City: Cluj-Napoca	*GIS*	*2D, no downloadable*	https://gis.primariaclujnapoca.ro/Public/		
	GIS Metropolitan Area	2D, all data downloadable at once. Terrain is not processed by the Publisher	https://beta.getlayer.xyz/cluj		
	Data	**Comments**	**Data**	**Description**	**Metadata**
State: Cluj	*Open data root*		https://cjcluj.ro/harta-digitala-a-judetului-cluj/		
	Data	**Comments**	**Data**	**Description**	**Metadata**
Country: Romania	*Open data root*		https://data.gov.ro/en/		
	Terrain	Processed	https://geoportal.ancpi.ro/portal/home/item.html?id=684ce69283c54612a3f2dd1ed7a306ff		
	Solar potential	unclear how to make use of it (grey scale images) and outdated as well (2016)	https://data.gov.ro/en/dataset/harta-potentialului-energetic-solar		
	Wind potential	unclear how to make use of it (grey scale images) and outdated as well (2016)	https://data.gov.ro/en/dataset/harta-potentialului-energetic-eolian		
	Orthophotos	not possible to use since EPSG=3844, required would be 4326 or 3857	*https://geoportal.ancpi.ro/portal/home/webmap/viewer.html?useExisting=1*	https://geoportal.ancpi.ro/maps/rest/services/Ortofoto/Ortofoto2012/MapServer/tile/	
			https://geoportal.ancpi.ro/maps/rest/services/Ortofoto/Ortofoto2016/MapServer/tile/{TileMatrix}/{TileRow}/{TileCol}		

6.1.1.1 Current Status: Cluj-Napoca Digital Model

Buildings and Orthophoto: VCS could not figure out data for buildings either in 3D or building footprints. Current orthophotos could not be found either. So, in general, creating a basic LDT would be hard. If no 3D data or footprints are available, VCS could create something from OSM, but official city data would be preferred.

Figure 30: Estimated current State of Cluj-Napoca-LDT acc. to Maturity Model

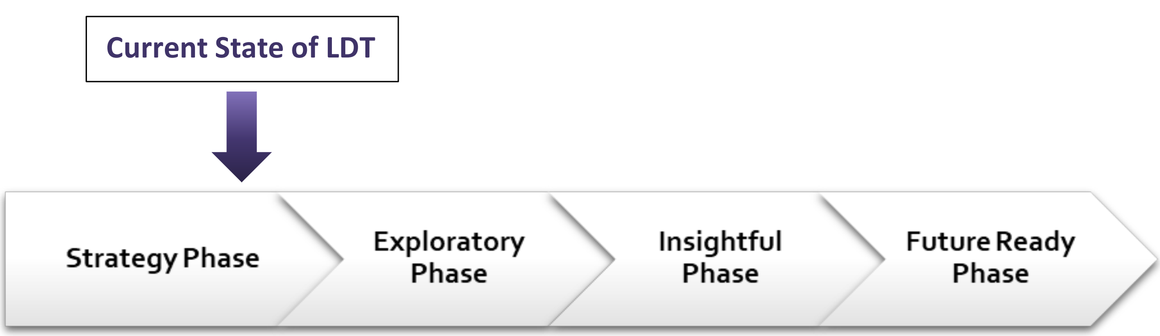


Table 8. Basic dataset availability in Cluj-Napoca-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1			✗
	LOD2			✗
	LOD3			✗
	mixed		OSM data	✓
3D surface model				✗
3D terrain				✓
3D Trees				✗
digital ortho photo		✓	From Satellite images (rough resolution)	✓
topographic map			OSM	✓

Figure 31: LDT of Cluj-Napoca

6.2 Follower City – Plzen

Besides the basic content of the LDT, some specific content is introduced. An overview of the specific content is given below.
The LDT is available at. https://urbreath.virtualcitymap.de/plzen/

Collection of geospatial data

Since the city of Plzen was part of the former DUET project, as well as VCS, VCS reused the data from DUET project for basic LDT creation. Thus, trees, buildings and terrain data are available from DUET project. Below some further specific datasets are listed.

Figure 32: Overview of specific datasets for the city of Plzen

	Data	Comments	Data	Description	Metadata
City: Plzen	*root open data*		*https://opendata.plzen.eu/*		
	GIS		*gis.plzen.eu*		
	Orthophoto	Do not cover the whole city	https://opendata.plzen.eu/public/opendata/detail/149		
	Trees	Already in the map	https://opendata.plzen.eu/public/opendata/detail/163		
State: Plzeň-město	**Data**	**Comments**	**Data**	**Description**	**Metadata**
	Open data root		*/*		
Country: Czech Republic	**Data**	**Comments**	**Data**	**Description**	**Metadata**
	Open data root		*https://data.gov.cz/*		
	Orthophoto	Processed	https://geoportal.cuzk.cz/(S(yfxv52znvlejuunhjnk2sc4f))/Default.aspx?lng=EN&mode=TextMeta&side=ortofoto&metadataID=CZ-CUZK-ORTOFOTO-R&productid=63410&mapid=83&head_tab=sekce-02-gp&menu=231	*https://data.gov.cz/dataset?iri=https%3A%2F%2Fdata.gov.cz%2Fzdroj%2Fdatov%C3%A9-sady%2F00025712%2F55115df1891857eb6a0a104289767f1e*	

6.2.1.1 Current Status: Plzen Digital Model

Figure 33: Estimated current State of Plzen-LDT acc. to Maturity Model

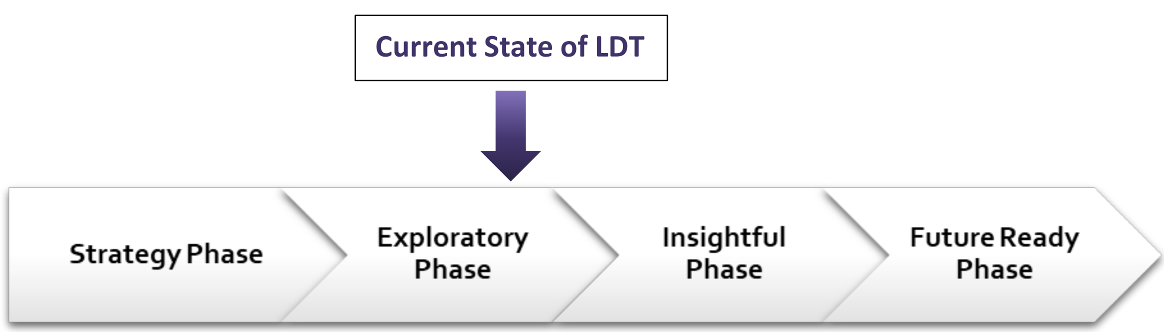
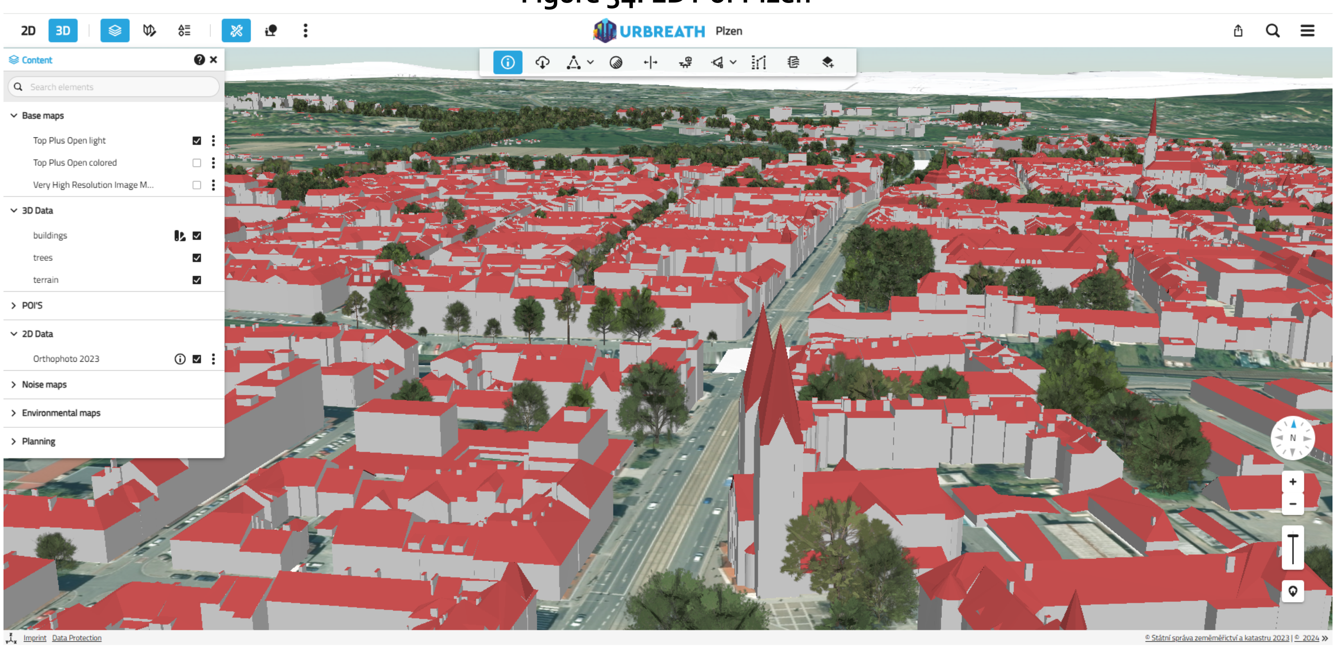


Table 9. Basic dataset availability in Plzen-LDT

dataset	characteristic	textured	type	availability in Urbreath-LDT
3D buildings	LOD1			✗
3D buildings	LOD2		CityGML	✓
3D buildings	LOD3			✗
3D buildings	mixed			✗
3D surface model				✗
3D terrain			with breaklines	✓
3D Trees		✓		✓
digital ortho photo		✓	From city (2023)	✓
topographic map			various	✓

Figure 34: LDT of Plzen

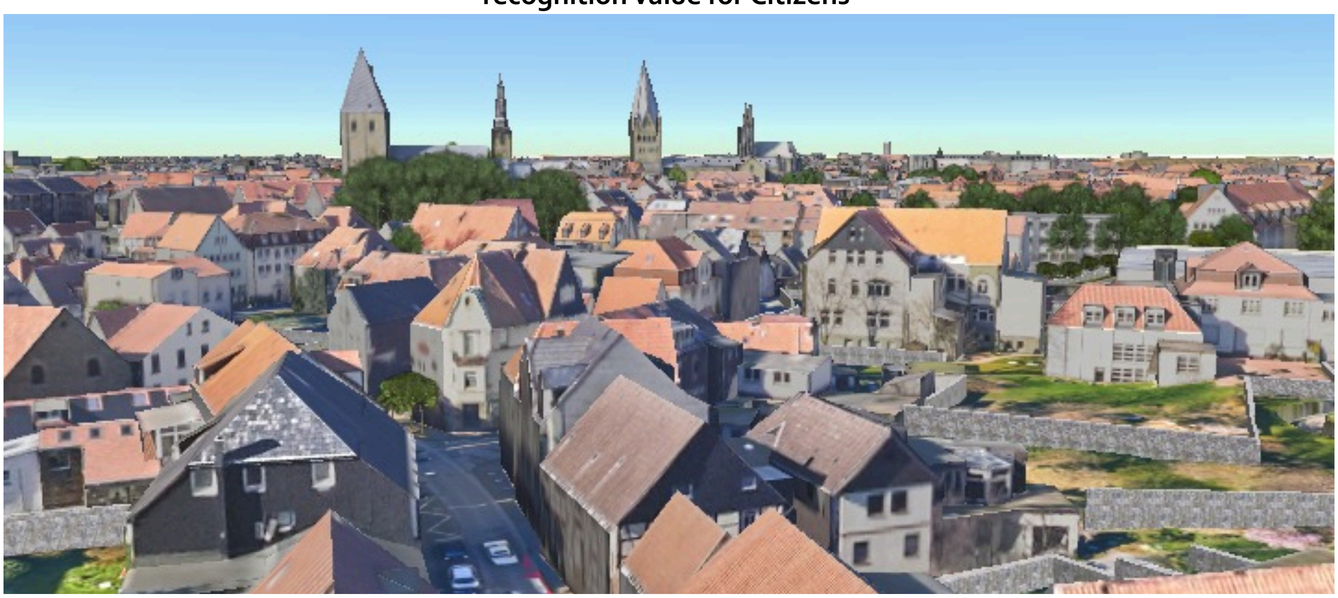


7 Summary of Data Availability and Modelling Challenges for LDT creation

While there is a broad range of datasets available to support the development of Local Digital Twins (LDTs), substantial disparities in data quality, type, and accessibility across cities pose challenges for accurate modeling. Basic 3D data such as buildings and terrain are often missing, particularly in smaller municipalities or regions where digital infrastructure is less mature. Extended datasets, including detailed environmental features like trees, tree cadasters, and other green infrastructure, are also typically unavailable. Moreover, 3D photorealistic data, such as high-resolution mesh models that offer detailed visual accuracy, is provided only in rare cases, with Aarhus being a notable exception. Textured 3D building models are, giving a photorealistic view, in all cases not available or at least not found.

Even when 3D building models are provided, they are generally untextured, limiting the visual realism and accuracy of digital representation. These issues in data availability led to a low "recognition value", where the alignment between virtual models and the physical environment is compromised. As a result, achieving a seamless integration between the virtual and real world is difficult, which can hinder the LDT's effectiveness for urban planning, public engagement, and simulation tasks. Addressing these gaps will be essential for improving the fidelity and practical applications of digital twins, particularly as cities look to integrate such models into urban development and sustainability efforts.

Figure 35: Example of photorealistic LDT (City of Soest, Germany) with trees – creating high visual recognition value for Citizens



8 Storytelling and Its Role in Urban Digital Twins

The Power of Storytelling: Storytelling is a fundamental means of conveying complex ideas, connecting with audiences, and fostering understanding. By organizing information into a narrative, storytelling turns data into memorable, meaningful insights. Effective storytelling provides context, invokes emotions, and engages audiences in a way that raw data cannot, making it a powerful tool for education, persuasion, and community-building.

Storytelling in Urban Digital Twins: In the context of urban digital twins, storytelling plays a crucial role in making vast, complex city data accessible and relevant. Urban digital twins' aggregate data on city infrastructure, environment, population trends, and more, creating a highly detailed model of the urban environment. Storytelling in this setting brings the data to life by guiding users through these digital replicas with narratives that showcase how urban changes impact residents, infrastructure, and the natural environment.

For instance, digital twins can tell the story of climate adaptation by simulating how future floods might affect various neighborhoods, illustrating the importance of green infrastructure in protecting vulnerable communities. Similarly, digital twins can narrate the journey of a city's evolution, from planning to construction to everyday interactions, highlighting how changes in transport, housing, or green spaces influence quality of life. This approach not only aids policymakers in visualizing outcomes but also engages the public, making complex urban dynamics more relatable and understandable.

By integrating storytelling with urban digital twins, cities can better communicate challenges, showcase solutions, and foster a sense of community ownership over future developments. This narrative approach transforms the digital twin from a technical tool into an accessible platform that drives informed decision-making and inspires civic engagement.

Storytelling in NBS Context: Nature-Based Solutions (NBS) are approaches that use natural processes and green infrastructure to address urban challenges such as flooding, air pollution, and heatwaves. Storytelling can enhance understanding and support for NBS by showing the real-world impacts and benefits of green spaces, water management systems, and ecological restoration. When integrated with urban digital twins, storytelling helps illustrate how NBS projects contribute to resilience, improve urban livability, and foster a healthier relationship between cities and nature.

Examples of Storytelling for NBS in Urban Digital Twins:

1. **Urban Flood Mitigation through Green Infrastructure:** In cities prone to flooding, an urban digital twin could simulate heavy rainfall events and show the effects of implementing green roofs, permeable pavements, and expanded wetlands. Storytelling can guide the viewer through a "before-and-after" narrative—first illustrating flooding impacts in a scenario without NBS, followed by scenes showing how rain gardens, bioswales, and floodplains absorb excess water

and reduce flood risk. This story format helps the public and stakeholders visualize how green infrastructure can prevent damage to homes, roads, and businesses.

2. **Heat Island Reduction through Tree Planting and Green Corridors:** Urban areas experience higher temperatures due to concrete and asphalt surfaces that absorb and retain heat. A digital twin could use storytelling to show how strategically placed trees, and green corridors mitigate the urban heat island effect, particularly in vulnerable neighborhoods. The narrative might follow a “day in the life” during a summer heatwave, highlighting how cooling zones, shaded walkways, and green parks reduce heat exposure for residents. This story demonstrates the measurable health benefits of NBS, including lower risks of heat-related illnesses and improved air quality.
3. **Biodiversity Restoration and Community Wellbeing:** Digital twins can help tell the story of rewilding urban areas, such as transforming an unused plot of land into a habitat for pollinators and native plant species. Storytelling can create a “seasons of change” narrative, illustrating how the area evolves over time and becomes a community asset. The narrative could focus on benefits such as increased biodiversity, spaces for recreation, and the mental health advantages of green spaces. By showing these long-term benefits, digital twins help communities understand how NBS projects like wildflower meadows, rain gardens, or urban forests foster wellbeing and create a richer, more sustainable urban environment.
4. **Water Quality Improvement with Natural Water Management:** In cities with pollution-prone waterways, a digital twin can model the effects of NBS like riparian buffers, overgrown wells, or constructed wetlands. Storytelling can highlight how these solutions filter pollutants, improve water quality, and provide habitats for wildlife. A narrative might follow the journey of a single water droplet—from polluted runoff in a parking lot to purified water in a stream—illustrating how natural systems contribute to cleaner water. This approach makes the ecological benefits of NBS visible and relatable, helping to build public support for sustainable water management strategies.

The Impact of NBS Storytelling in Digital Twins: By leveraging storytelling, urban digital twins make the impacts of NBS tangible and inspiring. These stories enable cities to showcase the long-term benefits of NBS, encouraging public support, fostering environmental stewardship, and aligning stakeholders around a shared vision for a resilient, nature-integrated future.

Storytelling with Virtual City Systems (VCS) in Urbreath Project

Virtual City Systems (VCS) offers a simple storytelling tool that will be introduced to the Urbreath project, providing cities with a powerful way to communicate their Nature-Based Solutions (NBS) initiatives. This storytelling tool will leverage the Local Digital Twins (LDTs) created within the project, giving cities an interactive way to demonstrate the impact of NBS through narrative-driven visualizations and simulations.

By using the VCS storytelling tool, cities can craft engaging stories that highlight their unique NBS use cases—whether it's green infrastructure for flood management, urban tree canopies for cooling, or green corridors for biodiversity. This tool allows city planners and officials to guide audiences through a visual journey, presenting how specific NBS projects address urban challenges, improve residents' quality of life, and contribute to sustainability goals.

With the LDT as a foundation, the VCS storytelling tool transforms the LDT into relatable narratives that make complex environmental impacts understandable and compelling. For example, the tool could illustrate the cooling effect of tree corridors on hot city streets. This storytelling capability will empower cities involved in Urbreath to communicate the benefits of NBS effectively, fostering community support and help stakeholders appreciate the role of nature in urban resilience and livability.

Ultimately, the VCS storytelling tool enhances the Urbreath project by enabling cities to present their environmental efforts not just as LDT, but as dynamic stories that connect with citizens, drive engagement, and inspire further action towards sustainable urban development.

The VCS story telling tool will make use of the LDT created and will provide HTML elements to describe the story as well as interactive elements to take control of the LDT.
Means from the story telling part a reader is able to interact with the LDT, like enabling shadows, showcasing NBS planning scenarios and way more.

Storytelling Tool for Cities in the Urbreath Platform

The Urbreath platform will include an integrated storytelling tool designed by VCS for cities to create and share their Nature-Based Solutions (NBS) stories. Developed by Virtual City Systems (VCS), this tool empowers cities to bring their environmental and sustainability projects to life through dynamic narratives that engage the public and stakeholders.

As part of the project, VCS will create initial stories for each Front Runner City and Follower City, providing a foundation that highlights key NBS initiatives and their impacts. These initial stories will serve as examples, demonstrating how cities can use storytelling to communicate the benefits of green infrastructure, urban cooling solutions, biodiversity efforts, and more. To ensure that cities can fully leverage this tool, VCS will also provide comprehensive training, equipping city representatives with the skills to develop their own NBS stories within the Urbreath platform.

Through this storytelling tool, cities will be able to showcase their unique NBS projects in an accessible, visually compelling format, building greater public awareness, support, and understanding of sustainable urban transformation.

Stories can be found here:

https://urbreath.virtualcitymap.de/stories/

Below you will find some screen shots from VCS created Aarhus NBS Story.

Figure 36. Aarhus initial story about their NBS site and NBS use case

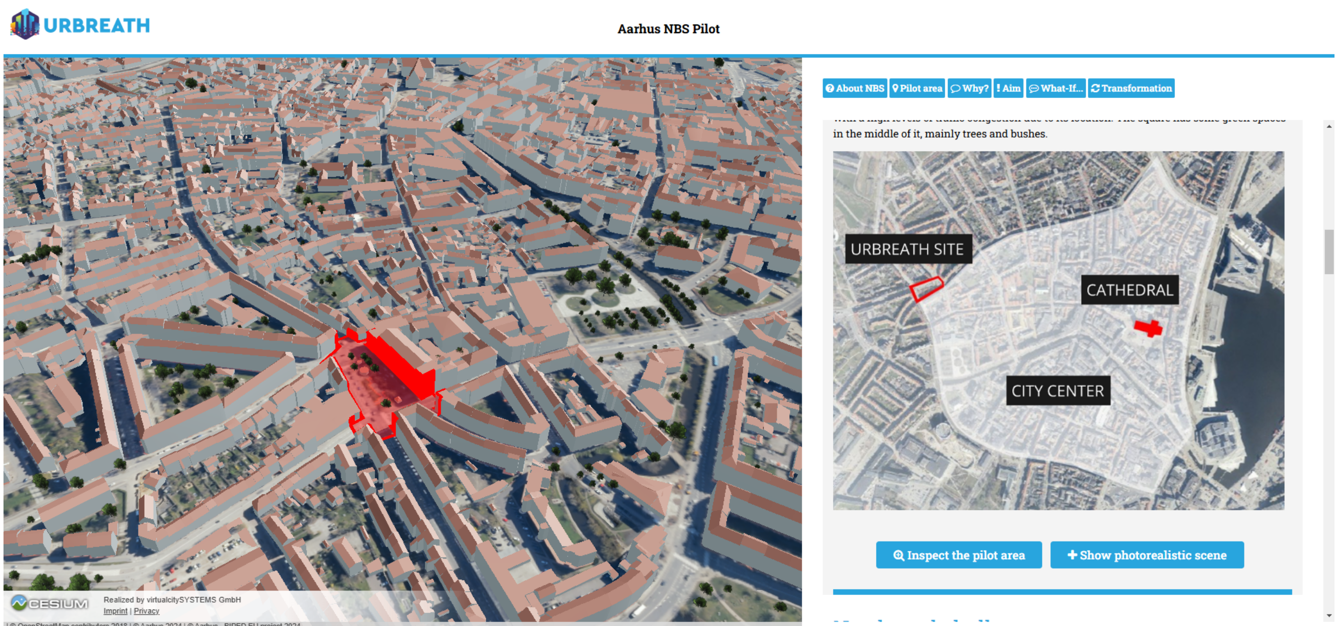


Figure 37: Story presenting effects of Traffic and Noise

9 KPIs catalogue

9.1 Requirements & Definitions

A KPI management tool for Nature-Based Solutions (NBS) is a specialized software component integrated into a broader architecture for managing and monitoring nature-based solutions.

9.1.1 What are KPIs and metrics?

- **Indicators** serve as qualitative or quantitative variables that enable the assessment of a particular phenomenon or attribute in relation to a defined objective.
- **Metrics** are explicitly calculated or composite measures or values based on two or more measurements, for example, before and after the implementation of an NBS.
- **KPIs (Key Performance Indicators)** are selected from the multitude of possible metrics and provide information on the performance of NBS measures regarding specific goals, such as reducing CO2 emissions or improving water quality.

9.1.2 Importance of KPI Selection

Choosing the right KPIs is crucial for the effective evaluation of NBS. The following factors play an important role:

- **Challenges:** The specific challenges to be addressed by NBS implementation must be clearly defined.
- **Goals:** The goals of the NBS implementation, such as improving air quality or increasing biodiversity, must be precisely formulated.
- **Impacts:** The scope of the expected impacts, i.e. whether they are local, regional or supra-regional, influences the selection of KPIs.
- **Resources:** The resources available for data collection and analysis must be considered when selecting KPIs.

9.1.3 KPI Management in Practice

Managing KPIs involves several steps:

1. **Establishing a baseline:** Before implementing the NBS, a baseline is established for each KPI. This serves as a reference point for evaluating the performance and impact of the NBS compared to a defined initial state. The baseline can be created using publicly available data sources such as municipal statistics, weather data, water quality data or traffic data.
2. **Data collection:** Suitable metrics and data collection methods are selected for each KPI. The sources offer a variety of methods that can be used depending on the indicator and available resources.
3. **Data analysis and interpretation:** The data collected are analyzed and interpreted to evaluate the performance of the NBS in relation to the defined KPIs.

4. **Reporting and adaptation:** The results of the KPI assessment are regularly communicated to the relevant stakeholders. Based on the results, adjustments can be made to the NBS implementation or KPI management, if necessary.

9.1.4 An example: The "Rocket Framework" [9]

An example for KPI management is, the "Rocket Framework", for defining KPIs for NBS in the context of landslides and erosion. The framework provides a structured approach to identifying KPIs at different stages of the NBS project:

- **Baseline:** Determining the initial situation and context of the project, including the characterization of hazards and risks.
- **Selection:** Defining selection criteria for suitable NBS based on technical aspects and stakeholder needs.
- **Implementation:** Planning and implementing the selected NBS measures.
- **Monitoring:** Monitoring the performance of the NBS over time using the defined KPIs.
- **Upscaling:** Transferring the knowledge and success of the NBS to larger scales.

The "Rocket Framework" helps to capture the multifunctionality of NBS and to consider both ecological and socio-economic aspects.

In summary, the effective selection and management of KPIs is crucial to evaluate and improve the performance and impact of NBS. The information and frameworks presented in the sources provide valuable tools and guidelines for this process.

9.2 NBS KPIs

Key indicators of NBS performance and impact

- **Carbon emissions**: This category includes indicators such as the total amount of carbon stored in vegetation or soil, the amount of carbon removed or stored per unit area and unit time, and the CO^2 emissions related to energy use by buildings and vehicle traffic.
- **Temperature**: Temperature indicators include local mean or maximum daily temperatures, heat stroke risk and the urban heat island effect.
- **Floods**: This category includes indicators such as flood peak height, time to flood peak, runoff to rainfall ratio and flood vulnerability.
- **Water quality**: Water quality is assessed using a variety of parameters, including nutrients, acidification, heavy metal contamination, total suspended solids content, and the total amount of pollutants discharged into local water bodies.
- **Green space management and biodiversity**: Indicators for green space management include the distribution and accessibility of green spaces, vegetation cover, biodiversity and green space quality.
- **Air quality**: Air quality is measured by the concentration of fine dust (PM10 and PM2.5), NO_2 and O_3 in the ambient air.
- **Economic activity and green jobs**: This category considers indicators such as job creation, gross domestic product (GDP), the amount of taxes paid by companies and the number of companies settling in the area surrounding the implemented NBS.
- **Participatory planning and governance**: This category assesses the extent to which the NBS project has contributed to the active participation of citizens in public decision-making, the development of new forms of NBS governance and policy learning regarding the adaptation of policies and strategic plans.
- **Social justice and social cohesion**: Indicators in this category include safety, including crime indicators, the number of people reached by the NBS project, the participation of vulnerable or traditionally underrepresented groups and gender equality.
- **Health and well-being**: This category includes indicators such as the promotion of healthy lifestyles, exposure to noise pollution, hospital admissions due to high temperatures during extreme heat events and the perceived impact of NBS on mental health and well-being.

9.3 KPI Manager

This section briefly presents the KPI Manager, which is a technical tool of the URBREATH Toolbox for the management and calculation of KPIs. The KPI Manager (part of the Digital Enabler platform) is designed to track, analyze, and manage key performance indicators effectively. Its primary purpose is to provide insights into the performance of various aspects of an organization, a project or a solution, facilitating decision-making and strategic planning. It acts as a central hub for aggregating data from various sources. The KPI Manager provides a unified view of performance metrics and consolidates data from various systems and databases. Through intuitive visualization tools such as dashboards, charts and graphs, the KPI Manager presents KPIs in a clear and accessible manner. This allows stakeholders to quickly see trends, patterns, and outliers within the data.

Customization is one of the main features of the KPI Manager, enabling users to define KPIs tailored to their specific business objectives and requirements. Users can set targets, configure alerts for deviations from desired performance levels, and adjust parameters as needed to reflect changes in strategy or priorities.

The tool tracks KPIs (Key Performance Indicators) over time, allowing users to monitor performance trends and identify areas for improvement or intervention. Historical data provides valuable insights into the impact of past decisions and initiatives on performance outcomes. Collaboration is facilitated through KPI Manager, which allows users to share KPIs, dashboards, and reports with relevant stakeholders.

The KPI Manager offers a Web UI designed to help monitor and manage KPIs for a project or organization clearly and straightforwardly. The UI is organized into different sections. In the following a short description of each section is reported.

Section #1 - Navigation Bar

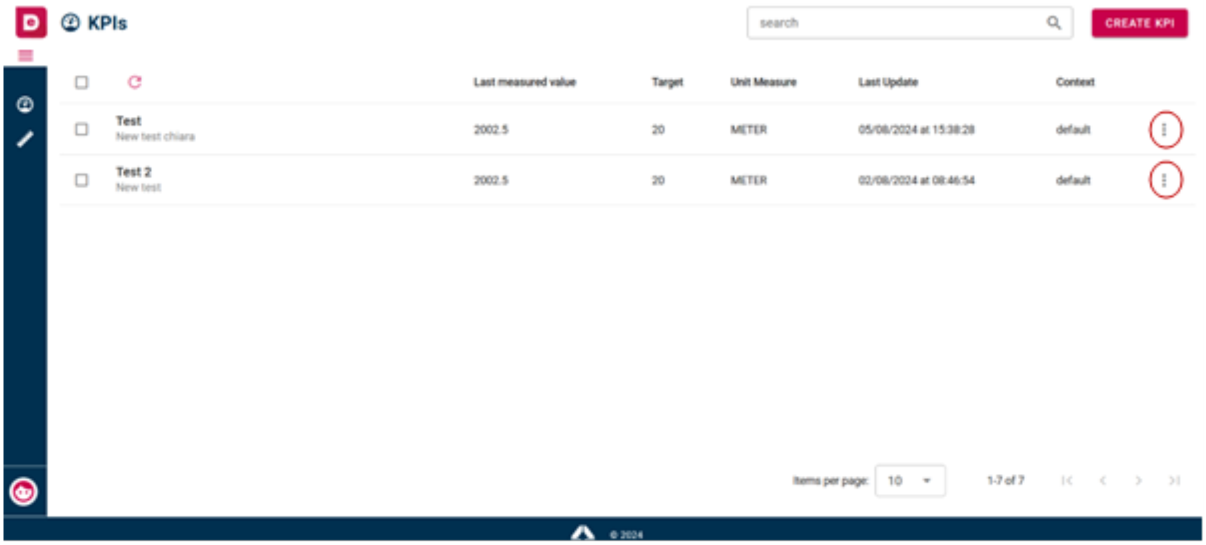
Figure 38: KPI Manager – Navigation Bar

Allows the user to quickly navigate through the steps of a KPI configuration:

- **Definition**: Provides details and a description of the KPI.
- **Formula**: Configuration of calculation formulas.
- **Dashboard**: Adds the KPI to the dashboard.
- **Summary**: Final review before saving.

Section #2 - List of KPIs

Figure 39: KPI Manager – List of KPIs



This section is the home page of the KPI manager, and it aims to offer access to the already defined KPIs and the main actions the user can perform on them (e.g. create, update, delete, etc.). KPIs are displayed in a table, where each row represents a specific KPI and reports the following information. Each row represents a specific KPI with the following details:

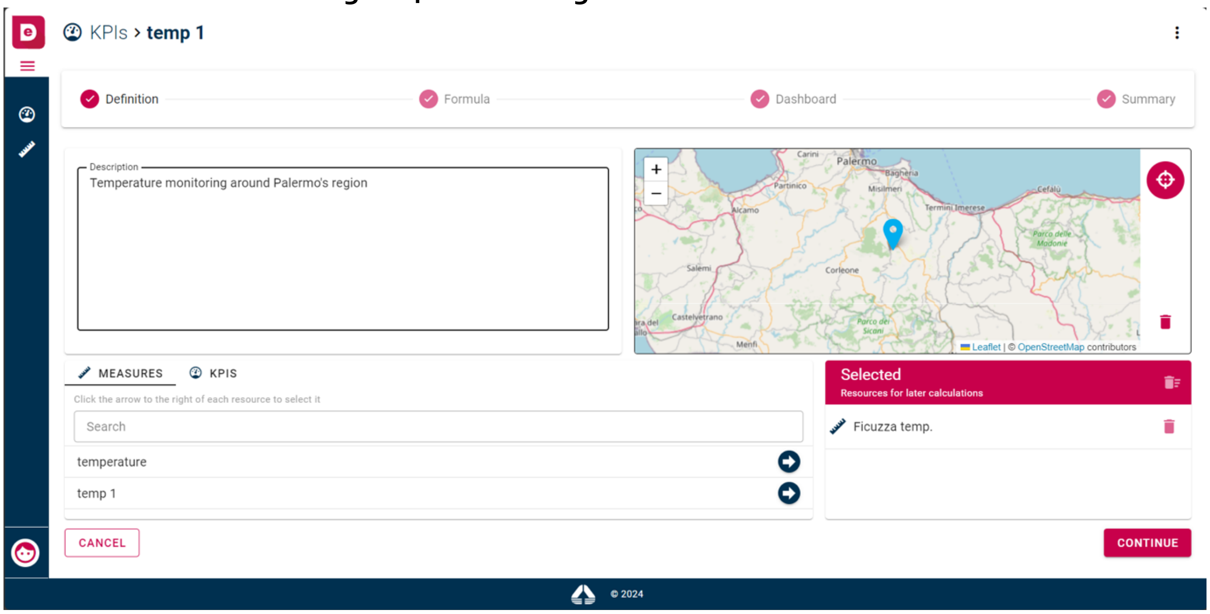
- **KPI Name**
- **Last Measured Value**: Shows the most recently recorded value.
- **Target**: Indicates the desired value for each KPI
- **Unit Measure**: Specifies the unit of measurement associated with the KPI (e.g., Celsius, Millimeter or KWh).
- **Last Update**: Displays the date and time of the latest modification.
- **Context**: Specifies the context to which the KPI belongs (e.g. all users, Admins etc.)

The user can click on the three vertical dots next to a KPI (circled in red) to open a menu with several actions:

- **Duplicate**: Create a duplicate of the selected KPI.
- **Compare**: Compare the KPI with others.
- **Export**: Export the data associated with the KPI.
- **Share**: Share the KPI with other users.
- **Delete**: Delete the selected KPI.

Section #3 - Definition of a KPI

Figure 40: KPI Manager – Definition of a KPIs

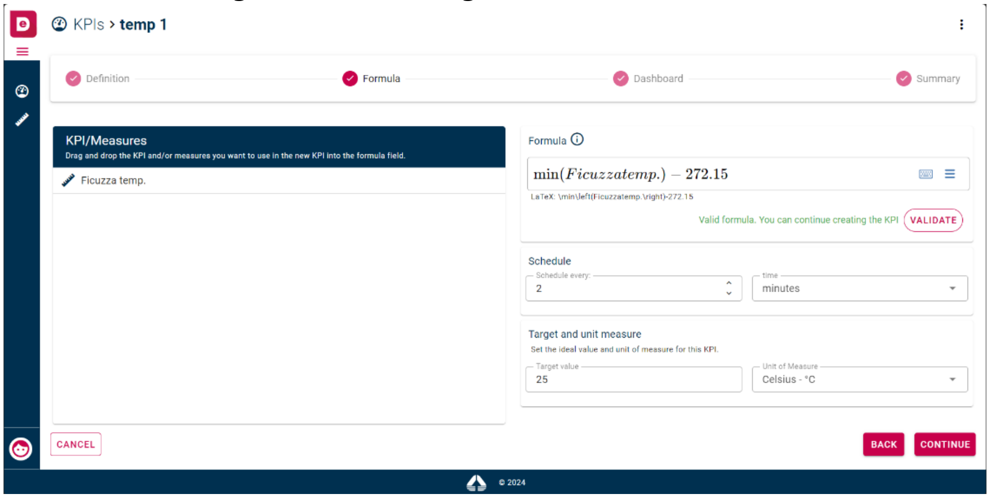


This section is designed to be the defining part of creating or updating a KPI, and is divided into three main functionalities, which collectively allow for comprehensive KPI customization:

- **KPI Description Field**: users can write a brief explanation of the KPI's objectives, which helps to communicate its significance to other stakeholders.
- **Geolocation Map Feature**: the interactive map on the interface enables users to select specific geographical areas or locations that the KPI will focus on, further clarifying the area focus of the KPI.
- **Measures and KPI selection**: to calculate a KPI, users need to specify the measures and existing KPIs that form its basis. This functionality enables users to select the necessary components, ensuring that the configuration aligns with the available data sources and metrics.

Section #4 - Formula for the KPI

Figure 41: KPI Manager – Formula for the KPI

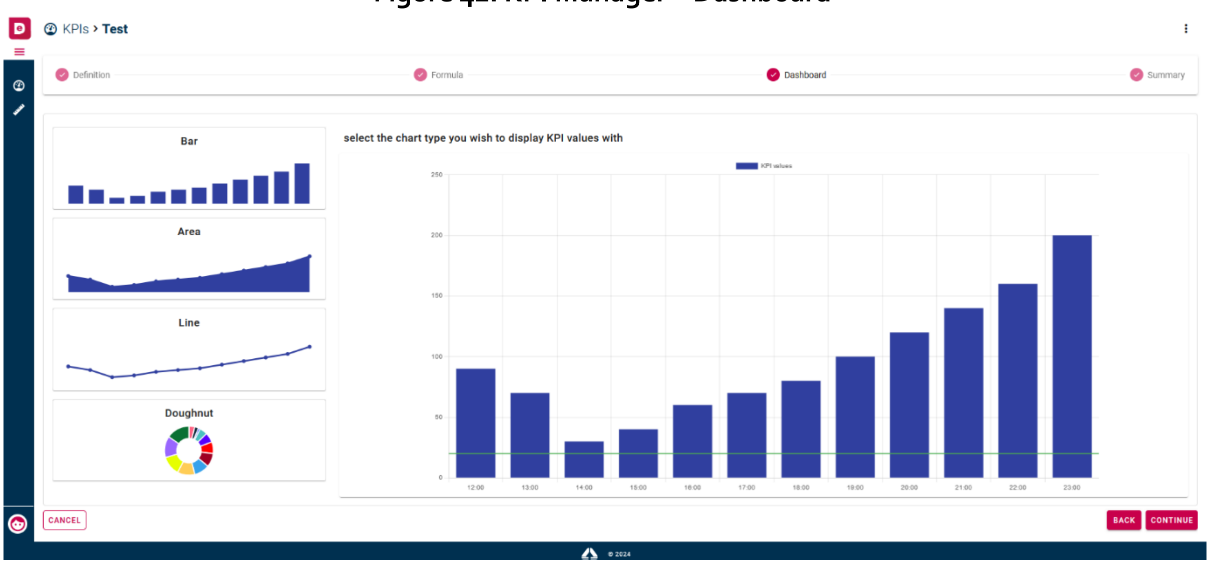


When creating a KPI, there might be a need to apply specific values or properties to the data received. For example, if the temperature API provides values in Kelvin, users can convert it to Celsius by subtracting 272.15. This adjustment can be set automatically in the formula to ensure consistent results.

The user also specifies its update schedule and sets its target value and measurement unit. The logic embedded in the application will ensure that the formula is well written and producing a valid result, before proceeding to the next steps.

Section #5 - Dashboard

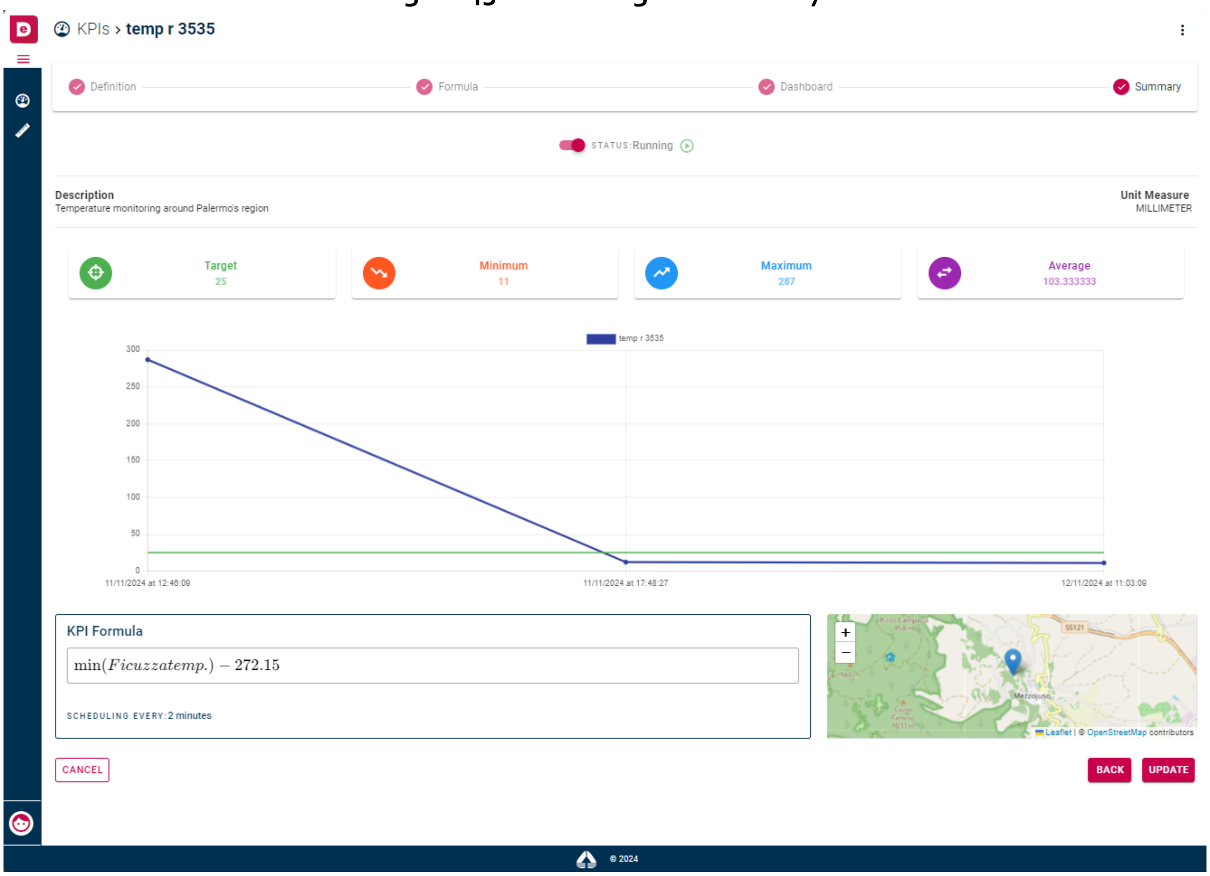
Figure 42: KPI Manager – Dashboard



The Dashboard section enables users to visualize KPI data through various chart types, including bar, area, line, and doughnut charts. These options cater to diverse analytical needs, such as comparing values, highlighting trends, or showing proportions.

Section #6 - Summary

Figure 43: KPI Manager – Summary



The summary is a monitoring dashboard for the configured KPI, allowing users to review real-time statistics, observe trends, adjust settings, and ensure that the KPI operates within the intended parameters. It is designed to provide a quick overview, helping users to identify trends and outliers in the data.

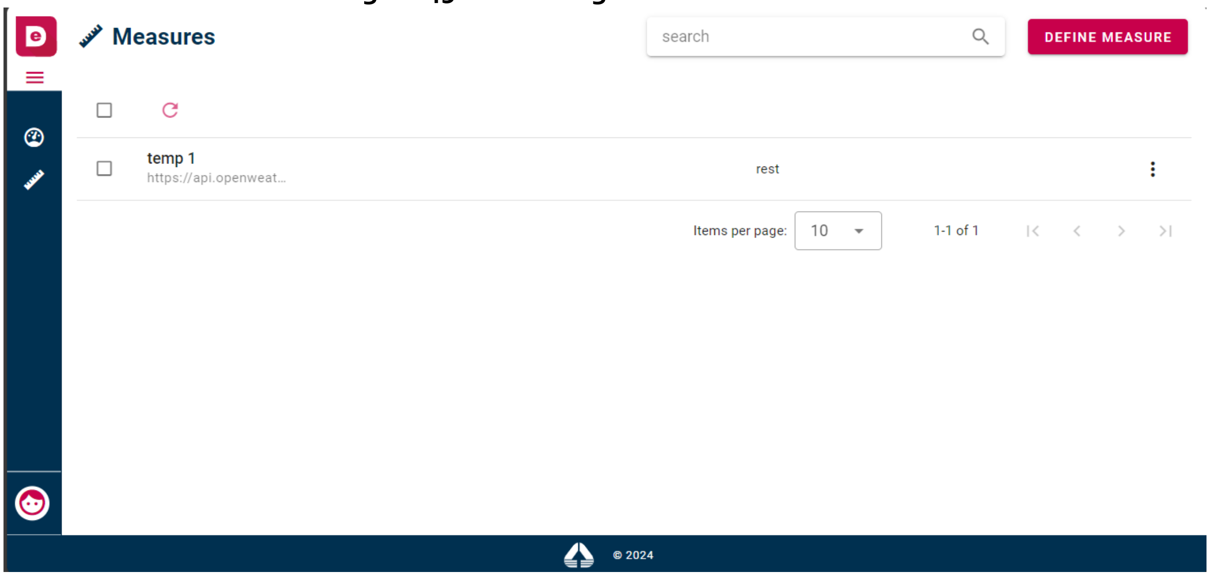
Section #7 – Compare

Figure 44: KPI Manager – Compare

The Compare section allows users to visually analyze and compare data from multiple KPIs within a single interface. Users can select the datasets to compare and choose different visualization options, such as bar, line, and stacked charts, making it easier to highlight specific aspects of the comparison. Whether focusing on trends, direct differences, or cumulative values it is designed to help the users identify performance gaps and trends effectively.

Section #8 - List of measures

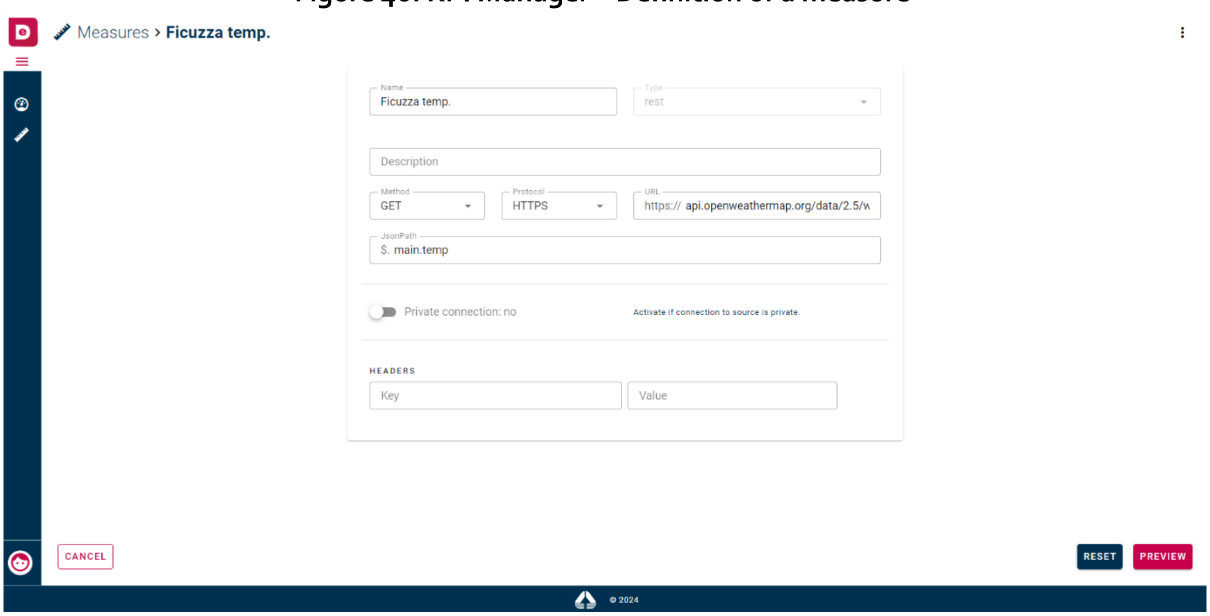
Figure 45: KPI Manager – List of measures



In the KPI Manager, a measure is the unit through which the user obtains the data needed for the monitoring of the KPI.

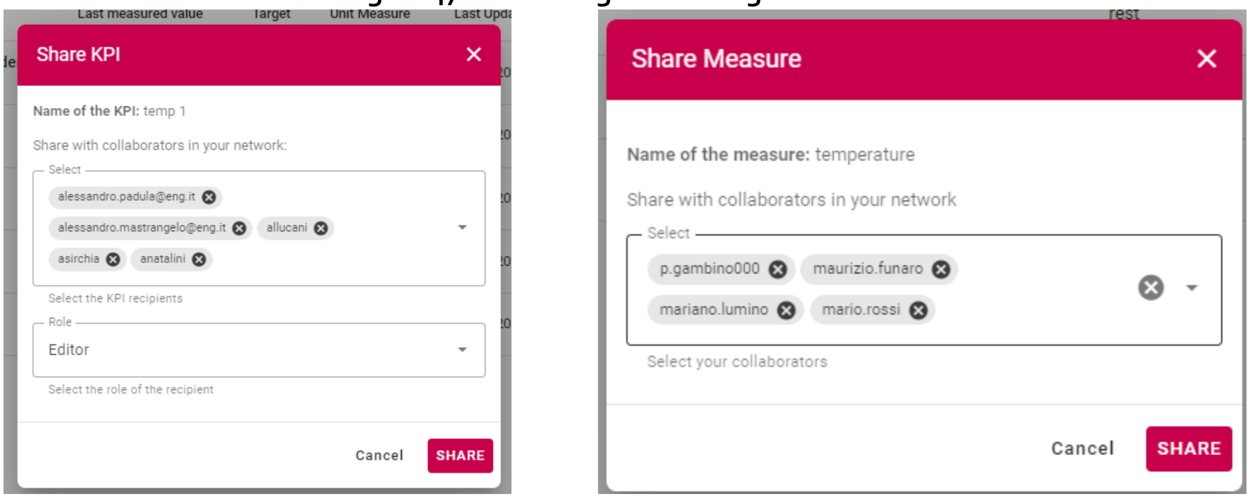
Section #9 - Definition of a measure

Figure 46: KPI Manager – Definition of a measure



This section is used to set up a measure that retrieves specific data from an external API. It includes fields for defining the request type, URL, data path and any necessary headers, allowing users to tailor how the measure interacts with the external data source.
Section #10 - Sharing forms

Figure 47: KPI Manager – Sharing forms



Each KPI and measure created can then be shared with one or more collaborators inside the same organizations, granting them access to that source as either Editor or Viewer (KPI only).

9.3.1 Technology stack

The KPI Manager is made of a Web UI (i.e. frontend) and a backend. The following sections offer the main technical details of both the frontend and the backend of the KPI Manager.

Frontend

The Web UI primarily utilises Vue.js[13] with Vuetify[14] as a component library, and Single-SPA[15] to implement a microfrontend architecture. A little bit more in depth:

- **Vue.js**: Vue.js is a progressive JavaScript framework used for building user interfaces. It provides reactive and component-based architecture, making it easier to create complex applications by breaking them down into fewer manageable components. Vue.js is known

[13] https://vuejs.org/

[14] A collection of components designed for Vue.js. https://vuetifyjs.com/en/

[15] https://github.com/single-spa/single-spa

for its simplicity and flexibility, allowing developers to efficiently create interactive web applications.

- **Single-SPA**: Micro frontends is an architectural style where a front-end application is split into smaller, more manageable pieces or "micro-apps" that can be developed, tested, and deployed independently. This approach is beneficial for large applications, as it enables teams to work in parallel, reduces dependencies, and facilitates scaling by allowing different parts of the application to evolve separately.

Using micro frontends allows for the KPI Manager to be part of a larger platform, the ENG's Digital Enabler ®, while maintaining flexibility and modularity. It also helps different teams to work on various sections independently, streamlining the development process and making maintenance easier. By combining Vue.js with micro frontends, the platform benefits from both the versatility of Vue components and the scalable, modular architecture provided by Single-SPA. This setup ensures that updates and new features can be deployed without impacting other parts of the platform.

Backend

The backend implements the logic application of the different functionalities of the KPI Manager. It is based on four core technologies/frameworks (summarized in the table below), which have been chosen to align with modern development practices while accommodating the scalability and flexibility needs of the KPI Manager.

Table 10. KPI Manager core technologies/frameworks

Technology/Framework	Version	Short description
NodeJS	20	Node.js is a JavaScript runtime environment that is used to implement command line tools and server-side applications.
Typescript	5	TypeScript is a programming language for the development of for both client-side and server-side applications (e.g. leveraging NodeJS).
InfluxDB	2.7	InfluxDB is a time series database.
PostgreSQL	16	PostgreSQL is a relational database management system.

The implementation id the backend is based on micro services, which are briefly summarized in the following.

- **Middleware microservice**: it acts as the central entry point for all other microservices. It handles authentication, authorization, and request validation, and manages caching to enhance performance and reduces redundant API calls. Finally, it provides administrative functionalities for managing project contexts and roles.
- **Measure Manager microservice**: it manages CRUD operations for "Measure" entities and connects to various data sources (e.g., REST APIs, SQL/NoSQL databases) via custom configurations. It supports multi-tenancy also with role-based access control for data visibility.

- **Manager Connectors microservice**: it interfaces with external data sources to fetch and structure data based on user queries that are needed to calculate KPIs. For this purpose, it supports various connection types and formats.
- **Indicators Manager microservice**: It allows to configure and manages KPIs, and store KPI definitions, formulas, and configurations in a metadata database. It orchestrates scheduled jobs (via CronJobs) to calculate KPI values at set intervals. Finally, it stores computed KPIs in a Timeseries Database (i.e. InfluxDB).
- **Listeners Manager microservice**: it provides access to historical KPI data (i.e. calculated values), also through the possibility to perform query.
- **KPI Formula Engine microservice**: It performs the calculation of KPI values by evaluates complex KPI formulas. It fetches data from the Measure Manager and Manager Connectors for real-time values. Furthermore, it incorporates historical data from the Listeners Manager as needed. Finally, it executes scheduled or on-demand formula evaluations.

10 Conclusions, Summary and Future Work

This document provides an overview of the work conducted under Work Package 4 of the URBREATH project, focusing on the implementation of Local Digital Twins (LDTs) using VC Publisher and VC Map. It highlights key topics and insights from data analysis, modeling challenges, and the integration of storytelling in LDTs. Additionally, a catalog of Key Performance Indicators (KPIs) is presented to monitor the effectiveness of LDTs and Nature-Based Solutions (NBS).

Key Topics and Insights:

1. Local Digital Twins as Decision Support Systems:

- **Definition**: A Local Digital Twin (LDT) is a virtual representation of a city or region that dynamically receives and processes real-world data to simulate the current state and behavior of its physical counterpart in real time.
- **Purpose**: LDTs serve as decision support systems for various stakeholders in the city, including municipal administrations, policymakers, urban planners, emergency responders, and citizens.
- **Benefits**: Improved decision-making, more efficient urban planning, optimized resource utilization, enhanced citizen engagement, and better disaster preparedness.

2. Data Foundations for Creating LDTs:

- **Geospatial Data**: 3D models of buildings, terrain, infrastructure, vegetation, and water bodies.
- **Demographic Data**: Population density, age distribution, socioeconomic indicators.
- **Environmental Data**: Weather conditions, air quality, noise levels, water quality.
- **Traffic Data**: Traffic volume, flow, and parking space usage.
- **Sensor Data**: Real-time IoT sensor data on various urban aspects.

3. VC Publisher and VC Map:

- **VC Publisher**: A platform for creating and managing digital twins that supports data integration, modeling, and continuous updates.
- **VC Map**: An open-source framework for visualizing geospatial data on the web, offering both 2D and 3D representations.

4. Challenges in Modeling LDTs:

- **Data Availability**: Variations in data quality, type, and accessibility across different cities.
- **Data Integration**: Combining diverse data sources and formats into a cohesive model.
- **Modeling Accuracy**: Creating detailed and realistic models that accurately reflect the physical counterpart.

5. Storytelling in Urban Digital Twins:

- **Significance**: Storytelling makes complex urban data more accessible and relevant by presenting information in a narrative format.
- **Use Cases**: Illustrating the impacts of urban developments, simulating climate scenarios, and promoting NBS.
- **VCS Storytelling Tool**: Enables cities to create and publish interactive stories based on their LDTs.

6. KPI Catalog & Manager:

- **Definition**: KPIs are measurable values that track the progress and effectiveness of LDTs and NBS.
- **Categories**: Carbon emissions, temperature, flooding, water quality, green space management, biodiversity, air quality, economic activity, health, and well-being.
- **Importance**: KPIs facilitate data-driven decision-making, evaluate the effectiveness of measures, and optimize LDTs and NBS.

Future Work:

- Improving data availability and quality.
- Developing advanced modeling techniques.
- Integrating AI and machine learning into LDTs.
- Enhancing citizen engagement through storytelling.
- Creating a comprehensive KPI dashboard.

Quotes:

- “Digital twins are expected to become an integral part of smart city development, helping cities become more efficient, sustainable, and livable.” (Page 11)
- “Integrating storytelling into urban digital twins enables cities to better communicate challenges, present solutions, and foster a sense of shared responsibility for future developments.” (Page 49)

Conclusion:

Local Digital Twins (LDTs) represent an emerging technological framework with significant potential to advance urban planning and management through the integration of real-world data and digital simulations. By enabling the analysis and optimization of urban strategies before implementation, LDTs provide a robust platform for evaluating the multifaceted impacts of Nature-Based Solutions (NBS), including environmental, social, and economic dimensions. Their capacity to simulate scenarios such as urban greening initiatives, stormwater management systems, and biodiversity-enhancing interventions positions them as critical tools for evidence-based decision-making in urban sustainability.

A key advantage of LDTs lies in their ability to facilitate citizen engagement, a fundamental component of inclusive and effective urban planning. Interactive LDT platforms enable participatory processes by allowing stakeholders to contribute to planning decisions and by visualizing the potential outcomes of proposed interventions. When coupled with advanced storytelling methodologies, these platforms can convey complex datasets in intuitive, actionable formats, thereby improving public understanding and fostering collaboration among diverse stakeholders.

However, the current state of LDT development remains nascent, with several technical and methodological challenges requiring further research and innovation:

- **Data Gaps**: Addressing inconsistencies in data availability, completeness, and quality is critical for enhancing the fidelity of digital representations. Effective integration of heterogeneous data sources, including geospatial, environmental, and socioeconomic datasets, is essential for accurate modeling.

- **Storytelling Integration**: Developing systematic approaches for embedding narrative techniques into LDT platforms can improve the communication of analytical insights, particularly for non-technical audiences.
- **Interactive Citizen Platforms**: Designing participatory tools that are scientifically robust and user-friendly can strengthen public involvement in the planning and implementation of NBS while ensuring inclusivity and transparency.

By addressing these challenges, LDTs have the potential to become indispensable instruments in urban sustainability research, enabling rigorous scenario analysis and data-driven policy evaluation. The URBREATH project contributes to this evolving field by advancing methodologies for LDT development, including the integration of dynamic data, improved modeling techniques, and enhanced stakeholder engagement processes. Future research should prioritize the refinement of these tools to support the design of resilient and adaptive urban systems.

11 References

[1] https://digital-strategy.ec.europa.eu/en/library/local-digital-twins-forging-cities-tomorrow.
[2] https://oascities.org/three-key-challenges-towards-digital-twin-adoption-at-scale/.
[3] https://eurocities.eu/latest/local-digital-twins-empower-urban-planners-for-informed-decisions/.
[4] https://www.linkedin.com/pulse/unlocking-city-potential-local-digital-twins-data-spaces-jara-sujwf.
[5] https://documentation.mindsphere.io/MindSphere/apps/factory-twin/creating-new-digital-twin-model.html.
[6] https://errin.eu/calls/towards-networked-local-digital-twins-eu.
[7] https://vc.systems/en/solutions/digital-twin/.
[8] https://www.nist.gov/publications/data-requirements-digital-twin-robot-workcell.
[9] Gonzalez-Ollauri Alejandro, Munro Karen , Mickovski Slobodan B. , Thomson Craig S. , Emmanuel Rohinton, 2021. The 'Rocket Framework': A Novel Framework to Define Key Performance Indicators for Nature-based Solutions Against Shallow Landslides and Erosion, https://www.frontiersin.org/journals/earth-science/articles/10.3389/feart.2021.676059.
[10] **Zhou, J., & Li, M. (2021).** *"Recognition of Digital Twin Models by Urban Inhabitants: A User-Centric Approach."* ISPRS Journal of Photogrammetry and Remote Sensing. https://www.sciencedirect.com/science/article/pii/S2226585623000249.
[11] Azarby, S.; Rice, A. Understanding the Effects of Virtual Reality System Usage on Spatial Perception: The Potential Impacts of Immersive Virtual Reality on Spatial Design Decisions. *Sustainability* **2022**, *14*, 10326. https://doi.org/10.3390/su141610326.
[12] Lei, B., Liang, X., and Biljecki, F.: Integrating human perception in 3D city models and urban digital twins, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., X-4/W5-2024, 211–218, https://doi.org/10.5194/isprs-annals-X-4-W5-2024-211-2024, 2024.

12 Annexes

(If needed)