

D3.3.1

EnCLOD guidelines on effective Open Data usage for territorial governance



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EnCLOD

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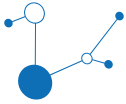
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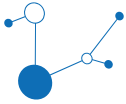
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1. Introduction

This document (D3.3.1) provides a final set of operational guidelines for local and regional policy-makers, technicians, and urban planners to exploit Open Data (OD) and Internet of Things (IoT) potentials for improved territorial governance. It builds on the preliminary guidelines developed in D1.3.1 during the first project year, integrating the full spectrum of findings, field experiences, and lessons learned from the five EnCLOD Pilot Actions, hackathons, capacity-building activities, and stakeholder engagement processes conducted across all project periods.

The document is structured in two parts. Part I presents the consolidated guidelines framework, addressing data governance, technical infrastructure, accessibility, organisational capacity, and impact measurement. Part II synthesises the practical evidence gathered from the Pilot Actions in Olomouc, Nova Gorica, Debrecen, Vicenza, and Zilina, illustrating how the guidelines were tested, adapted, and refined in real territorial contexts.



2. Part I - Starting guidelines

Municipalities across Central Europe face interconnected challenges: suburban sprawl and commuter pressure, climate impacts (heat islands, flooding), energy poverty, and fragmented cross-sectoral governance. Digital Urban Planning (DUP) - supported by open static and dynamic IoT sensor data - offers a pathway to evidence-based, cross-sectoral decision-making and a digital twin of the territory.

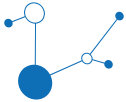
The EU's twin green and digital transition agenda frames this approach: IoT open data can support Green Deal investment planning while enabling bottom-up digital transformation regardless of city size. The core challenge for municipalities is practical: where to deploy sensors, how to ensure data reliability and interoperability, which standards to follow, how to publish data openly, and how to procure and sustain such services.

The preliminary version of these guidelines (D1.3.1) outlined these principles based on the State-of-the-Art Analysis. The present document (D3.3.1) validates and refines them through the practical experience of five Pilot Actions, hackathons, and capacity-building activities conducted across Central Europe between 2024 and 2026. The following sections present the consolidated framework (Part I) and the cross-pilot evidence base (Part II).

The technical standard drafted on the basis of EnCLOD results by the Czech partners - *Intelligent Transportation Systems: Digital Land-Use Planning, Supporting Territorial Governance Through Open Data on Mobility and Climate* - translates the project findings into a formal technical specification intended for national adoption. Three of its propositions are reflected throughout the present document: that the territorial reference framework must be defined before any hardware is procured; that the open data agenda increasingly has to be run at the scale of the Functional Urban Area (FUA) rather than the administrative territory of a municipality, because energy, commuting and climate pressures do not stop at municipal boundaries; and that the procurement of sensors should be reframed from HW delivery to the procurement of a data service. The standard defines two deficits - mobility poverty, the inability to reach work, school or a doctor because of poor connections, fare costs or the absence of suitable transport, and energy poverty, a household unable to meet basic energy needs because of low income, high prices and poor building efficiency - are among the policy problems that open IoT data is expected to make measurable at zone level.

2.1 Definition and Purpose

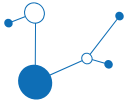
- **Open Data** refers to datasets made freely available to the public without restrictive licenses. It enables transparency, innovation, and collaboration.
- Its applications in urban planning include mobility **transportation, infrastructure, public services, zoning**, environment, climate change and **community engagement**.
- **City digital twin**: a dynamic virtual model of a real urban area that integrates spatial data, real-time data from IoT sensors and advanced simulation, used for infrastructure management, analysis of phenomena and development planning.
- **Digital urban planning**: a set of digital services for urban planning that combines open data, dynamic IoT data, machine learning and artificial intelligence to support green transition investment planning and the assessment of socioeconomic impacts within a functional urban area.
- **Microzones**: virtualised territorial units for independent strategic planning using static and dynamic open data. They are the reference framework against which all datasets are recalculated, compared and, where the data is sensitive, aggregated.



- **Geofencing:** zone-based traffic monitoring achieved by covering the entry and exit points of a microzone, either physically with detectors or by calculation from the profiles of main roads on the zone boundary.

2.2 Benefits of Using Open Data

1. **Transparency and Accountability:**
 - Allows citizens to monitor government projects and decision-making.
 - Builds trust in governance.
2. **Enhanced Planning:**
 - Provides insights into real-time and historical patterns (e.g., traffic flow, public space usage, climate change impacts).
 - Facilitates data-driven decision-making.
3. **Community Engagement:**
 - Involves citizens in the planning process through participatory tools.
 - Encourages crowdsourcing ideas for urban challenges.
4. **Economic Development:**
 - Supports startups and businesses leveraging data to create innovative services (e.g., mobility apps).
 - Reduces reliance on costly proprietary data.
5. **Efficiency and Cost Savings:**
 - Streamlines resource allocation.
 - Reduces duplication of effort among government agencies.



3. Methodology of OD and IoT in Local Governance Insights from the State-of-the-Art Analysis

3.1 Key findings of D.1.1.1 & D1.2.1

The EnCLOD state-of-the-art analysis (D1.1.1, D1.2.1) identified the following cross-cutting findings: environment and traffic data are ideal entry points for open IoT data, as they carry no personal data concerns; a holistic, citywide approach to sensor deployment - based on microzoning - is essential; data quality monitoring, clear terms for third-party access, and a publication service model must be designed from the outset; public engagement tools (dashboards, hackathons) are critical for demonstrating value and building ownership; and each pilot area should begin with a gap analysis aligned to its own city agenda.

Criteria for Success:

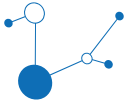
- **Scalability:** The ability to expand solutions across different contexts.
- **Sustainability:** Long-term viability of implemented practices.
- **Stakeholder Engagement:** Involvement of community and civil society in data initiatives.
- **Data Quality:** Ensuring high standards in data collection and processing

Challenges in data quality:

- **Data Quality and Accessibility:** Ensuring the quality and accessibility of open IoT data is a significant hurdle. Poor data quality can lead to ineffective decision-making and undermine public trust in IoT implementations.
- **Integration with Existing Infrastructure:** Integrating new IoT systems with existing urban infrastructure can be complex and costly, requiring careful planning and coordination among various stakeholders.
- **Security and Privacy Concerns:** The deployment of IoT devices raises concerns about data security and privacy, as cities must protect sensitive information from cyber threats while complying with regulations.
- **Funding and Resource Allocation:** Securing adequate funding for the initial setup and ongoing maintenance of IoT systems can be challenging, particularly in cities with limited budgets.
- **Stakeholder Engagement:** Engaging citizens and stakeholders in the planning and implementation of IoT projects is crucial but can be difficult, especially if there is a need for more awareness or understanding of the benefits of such technologies.
- **Scalability Issues:** Designing scalable IoT solutions to accommodate future growth and technological changes is essential but often overlooked during initial deployments.

An outstanding example is IPR Praha. The Prague Institute of Planning and Development develops and manages Prague's geographical data and performs spatial analyses of traffic accessibility, ownership relations within the city, and the structure of built-up areas, among others. Based on long term work on data they are now working with a 3D model with many data layers experimenting with AI (<https://geoportalpraha.cz/en/data-and-services/articles-and-projects/3D-model/3D-model-digitalni-dvojce>)

A second outstanding example, situated at the level of the instrument rather than the individual dataset, is the technical standard drafted from EnCLOD results, which converts the pilot experience of



Olomouc and Zilina into a specification addressing precisely the challenges listed above - data quality, integration with existing infrastructure, security and privacy, funding, stakeholder engagement and scalability - and which defined the conditions for the Olomouc digital twin tender. It is synthesised in full in Annex I to this deliverable.

3.2 Key findings of D.1.2.1

- **Environment and Traffic:** Ideal for open IoT data implementation without personal data concerns. A holistic approach should be adopted, demonstrated by a citywide IoT sensor map for traffic and environmental monitoring, with Olomouc as the pilot.
- **Drinking Water Data:** This can be openly accessed but should be aggregated by location and time to minimize misuse. A questionnaire targeting water companies can gather data for the Local Action Plans.
- **Wastewater Management:** Offers significant energy savings and demand for IoT solutions, but opening data access may present challenges. A questionnaire can be sent to wastewater companies to address this in the Local Action Plans.
- **Energy Data:** Currently difficult to open, but the Local Action Plan should explore ways to make some energy data accessible. This will be a lower priority and categorized as a “nice to have” component.
- **IoT Open Data Strategy:** Necessary for holistic IoT data provision. A micro zoning map should be created as a guide, building on best practices from Olomouc.
- **Sustainability of Data Sources:** Critical for overcoming barriers like low data quality and accessibility issues. The project will develop a strategy, technical standards, and a public dashboard for IoT open data.
- **IoT Operation Continuity:** Policy-level strategies and business models for long-term IoT operation as a public service will be developed as an outcome.
- **Sensor Placement:** The Olomouc case provides guidance for proper sensor placement, including traffic and heat island monitoring, with potential technical standards being explored by Czech partners.
- **Data Quality Monitoring:** Essential for ensuring accurate data, with a service for data quality monitoring being considered, including requirements and costs.
- **Data Storage and Publication:** Clear terms for third-party access must be established, and a service model for the publication of IoT open data will be created based on a policy-level analysis and Olomouc case study.
- **Public Engagement:** Tools for citizen interaction with IoT systems will be developed, including opportunities for citizen participation and a public dashboard displaying localized open IoT data.
- **City/Regional Needs:** Each pilot area should prioritize gathering needs based on a gap analysis and engage city staff to align the project with the city's agenda. A table of key use cases will guide the development of future software tools to support these needs.

This overview highlights the project's readiness for IoT-driven solutions while pinpointing specific areas for improvement. These findings will directly inform the guidelines for implementing Open Data initiatives in alignment with local priorities and the broader project goals.



3.3 Guidelines and the main OD issues through various levels

Purpose

To define tasks, responsibilities, and timelines for advancing the IoT and open data agenda in local action plans, supporting sustainable urban development and smart city governance. This document serves as a roadmap for developing local action plans.

*Open data initiatives are evaluated across 4 levels - (political, technical, expert and organizational level) and five key dimensions: **Data Quality**, emphasizing accuracy, completeness, and security compliance; **Accessibility**, ensuring user-friendly formats, regular updates, and easy access; **Interoperability**, promoting standardized formats and user engagement; **Governance**, focusing on clear policies, leadership, and stakeholder involvement; and **Impact**, highlighting economic, social, and environmental benefits, along with innovations driven by open data. These principles collectively enhance transparency, usability, and societal value.*

➤ Political level

Objective

Develop a long-term strategy for IoT deployment, focusing on digital urban planning and alignment with the European Green Deal.

Governance and policy

This dimension evaluates the governance and policy framework supporting open data.

- **Policy Framework:** Existence of policies supporting open data (e.g., open data policies, data privacy policies)
- **Leadership and Management:** Clear leadership and management structure for open data initiatives
- **Data Standards:** Adoption of data standards and interoperability protocols
- **Stakeholder Involvement:** Engagement with key stakeholders (government agencies, private sector, academia, civil society)

Impact

This dimension evaluates the impact of open data initiatives.

- **Economic Impact:** Evidence of economic benefits derived from open data (e.g., job creation, business development)
- **Social Impact:** Examples of social benefits (e.g., increased transparency, improved public services)
- **Environmental Impact:** Contributions to environmental sustainability and monitoring
- **Innovations and Improvements:** Notable innovations and improvements in services or governance enabled by open data

Key stakeholders:

Local government leaders, regional representatives, and policymakers will champion the strategy, ensuring alignment with national and EU priorities while actively engaging citizens in the planning process.



➤ Technical level

Objective

Ensure IoT data reliability, accessibility, and interoperability to support cross-sectoral urban management.

Data quality

This dimension evaluates the quality of the data provided.

- **Accuracy:** Correctness and reliability of the data
- **Completeness:** Coverage and comprehensiveness of the datasets
- **Consistency:** Consistency of data across different datasets and sources
- **Metadata:** Availability of comprehensive metadata describing the data
 - Ensure accuracy, timeliness, and completeness.
 - Validate sources to maintain reliability.
- **Privacy and Security:**
 - · Anonymize sensitive data to protect individual privacy.
 - · Follow legal frameworks such as GDPR (General Data Protection Regulation).

Key stakeholders:

IT specialists, IoT providers, and technical teams will oversee the deployment, management, and maintenance of the IoT network and associated platforms.

➤ Expert level

Objective

Address climate and traffic challenges using IoT-driven, holistic approaches that prioritize solutions requiring minimal personal data protection.

Accessibility and Availability:

This dimension evaluates the extent to which data is available for use by the public.

- Provide **user-friendly formats** (e.g., CSV, GeoJSON, APIs).
- **Avoid overly technical interfaces** to ensure inclusivity.
- **Datasets Published:** Number and variety of datasets published
- **Frequency of Updates:** Regularity and frequency of data updates
- **Accessibility:** Ease of access to the data (APIs, portals)

Key stakeholders:

Urban planners, environmental specialists, and data analysts will lead the technical and strategic deployment of IoT solutions in their respective domains.



Completeness:

This dimension evaluates the share of the coverage of IoT sensors in operation / other data sources on a holistically designed IoT sensors deployment.

- Provide the city and the community with potential targets as well as a state of the art of the IoT sensors coverage
- Provide a survey of the most used data/sensors and related/potential portfolio of digital services.
- Provide an insight on which staff/departments are advanced in using digital tools
- Support synergies in using as well as funding open IoT data

➤ Organizational level

Objective

Foster a local open IoT data ecosystem that encourages collaboration, innovation, and public awareness.

Interoperability and Data Use:

This dimension evaluates the extent to which the public uses data.

Use standardized data formats for seamless integration across platforms.

- **User Engagement:** Number and diversity of data users (citizens, businesses, researchers)
- **Applications Developed:** Number and impact of applications or services developed using the data
- **Case Studies:** Documented use cases demonstrating the data's utility

Governance and Policy:

- Define clear policies for data sharing and usage.
- Set up an open data portal to centralize access.

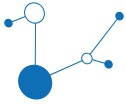
This dimension evaluates the governance and policy framework supporting open data.

➤ Urban branding

Urban branding refers to the strategic process of creating a unique and compelling identity for a city or urban area. It involves leveraging a city's characteristics, culture, history, and aspirations to promote its distinctiveness and enhance its reputation. Urban branding is often used to attract tourists, investors, businesses, and new residents, as well as to strengthen the sense of identity and pride among current residents.

Key Components of Urban Branding:

1. **City Identity:** Highlighting the unique traits of a city, such as its architecture, cultural heritage, or natural landscapes.
2. **Vision and Narrative:** Crafting a story or message that reflects the city's values, aspirations, and future direction.

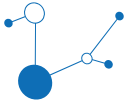


3. **Stakeholder Engagement:** Collaborating with local communities, businesses, and policymakers to ensure the branding aligns with the city's authentic character.
4. **Visual and Verbal Elements:** Designing logos, slogans, and other visual representations that embody the city's essence.
5. **Targeted Campaigns:** Using media, events, and marketing initiatives to communicate the brand to specific audiences, such as tourists, investors, or residents.

Benefits of Urban Branding:

- **Economic Growth:** Attracts businesses, tourists, and investments by showcasing the city's potential.
- **Cultural Promotion:** Enhances global awareness of the city's cultural and historical assets.
- **Community Cohesion:** Fosters a sense of belonging and pride among residents.
- **Global Competitiveness:** Helps the city stand out in a globalized world by emphasizing its unique selling points.

Urban branding is increasingly seen as a vital tool for cities to compete and thrive in a dynamic global landscape, blending marketing strategies with urban development goals.



4. Orienting the Open Data in the Pilot Areas

Strategy for the Use of Open Data (Based on Activities 1.1 and 1.2)

Developing a strategic orientation for Open Data in the pilot area requires aligning its application with local priorities and challenges, as identified in **Activities 1.1 and 1.2**. The strategy focuses on establishing a robust framework to guide data use in support of urban governance and sustainability goals.

4.1 How EnCLOD defined its Open Data strategy

The EnCLOD project established a common strategic framework for Open Data use across its pilot territories, built around three objectives:

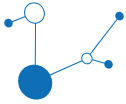
- enhancing evidence-based decision-making through continuous, reliable environmental and traffic data;
- promoting transparency by treating all sensor-generated datasets as a public good, openly accessible by default; and
- enabling innovation by publishing data in interoperable formats that invite reuse by citizens, researchers, and businesses.

This framework was operationalised through three pillars. Data governance required each pilot area to define clear responsibilities for data ownership, operation, publication, and long-term continuity - embedded within existing local strategies (smart city plans, SUMPs, climate adaptation plans) rather than treated as a standalone initiative. Data accessibility mandated publication in standardised formats (CSV, JSON, API) with structured metadata, open licences, and a common 15-minute aggregation interval as a practical standard across all sensor types. Stakeholder engagement was treated as a structural component: each pilot area was expected to organise capacity-building workshops, outreach to sensor hosts and communities, and at least one hackathon using the published datasets.

A distinctive methodological contribution was the holistic sensor network design based on microzoning - dividing the city into defined spatial zones aligned with existing statistical units, then designing sensor deployment as a complete logical model rather than placing sensors ad hoc. This creates a reference framework for cross-zone comparison, gap analysis, and future digital twin development.

A second methodological principle, formalised in the technical standard drafted from EnCLOD results, is to sequence data acquisition from the simplest source to the most complex. The foundation layer is static open data from international, national and other registries - census data, traffic surveys, property inventories, registers of economic entities - which is standardised, long-lived and therefore reliable. The second layer is data generated by technologies, whether collected once (satellite imagery, nationwide mobile operator data) or continuously (existing camera systems, IoT sensor networks, floating car data). The third and most resource-intensive layer is data collected by people: nighttime parking surveys, heat island measurement campaigns, commuting and public transport questionnaires, emotional mapping. The fourth layer consists of values calculated from the three beneath it, in the form of indices and coefficients - the real parking ratio per dwelling derived from nighttime surveys combined with sensor counts, or the greening potential of a parking area derived from occupancy data combined with heat island measurements. The fourth layer carries the greatest planning value, because it allows rigid quantitative land-use requirements such as a fixed share of green space to be replaced by qualitative, climate-responsive parameters. It is only reachable if the layers beneath it have been built in order.

Each pilot area was free to define its own thematic focus (mobility, air quality, heat islands, road safety, parking) within this common framework, testing its transferability across different scales, institutional settings, and policy domains.



4.2 What can be defined for new pilot areas

The EnCLOD framework is directly transferable. A new municipality or region seeking to introduce Open Data and IoT for territorial governance should follow a comparable sequence:

1. Identify a concrete policy entry point where demand for better data already exists or where an upcoming policy process creates a window of opportunity. Traffic and climate data are recommended starting domains - they require no personal data processing and serve multiple municipal agendas.
2. Map the territory through microzoning, creating a holistic spatial reference model before any sensors are deployed.
3. Conduct a gap analysis and match-mapping of existing data sources, technologies, and infrastructure to identify what can be opened without new hardware and where new deployment is needed.
4. Define data governance early - ownership, operation responsibilities, publication channels, licences, and a sustainability plan for post-funding continuity.
5. Procure by bundling hardware with data-service delivery (connectivity, dashboards, API access, metadata), requiring open formats and open licences as mandatory criteria.
6. Publish data as soon as the first sensors are operational, on established portals and dedicated dashboards, to build momentum and demonstrate value.
7. Engage stakeholders through workshops, community outreach, and hackathons anchored to concrete local use cases.
8. Measure progress through predefined KPIs (datasets published, user engagement, applications developed, policy decisions informed) and iterate based on feedback.

The same sequence can be expressed as a phased action plan, which is the form recommended by the technical standard drafted from EnCLOD results and the form most readily transferred into a municipal work programme. A preparatory phase (0.X), run by the municipality with a strategic partner, establishes an informal working group and formalises the agenda with data providers and technology operators. A data mapping phase (1.X) covers national and spatial statistics, local static open data, a register of potential dynamic data sources, and negotiations with the operators of existing IT and ITS systems such as intersection loops or barrier systems at hospitals and car parks. A territorial division and data collection phase (2.X) covers microzoning, the mapping of datasets to zones, the holistic sensor design with its acquisition and operating economics, and a feasibility check on aggregating water and energy data. An organisational and networking phase (3.X) covers the internal working group, partner identification, a local website and public dashboards, regular awareness events, hackathon preparation, delivery and evaluation, and successive rounds of staff training. A feedback and strategy phase (4.X) covers the collection of use cases, the matching of use cases to the datasets they require, a maintained list of digital services already on the market, twinning with comparable municipalities, and the formal adoption of the open data strategy and action plan with its timeline, budget, publication plan and staffing arrangements. Each activity should carry a named owner and a dated outcome.



5.Actions Towards the Advancement of Open Data

Advancing OD requires parallel actions across capacity-building, platform development, public engagement, and partnerships.

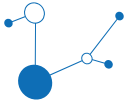
Training and capacity building: workshops for planners and officials on OD management, IoT integration, and data-driven decision-making; hands-on technical training on analysis and visualisation tools; public awareness campaigns.

Tools and platforms: launch a user-friendly Open Data portal with API access; develop interactive dashboards for real-time visualisation of traffic, air quality, and climate data; implement automated data quality monitoring.

Public and collaborative initiatives: hackathons and innovation challenges using OD (smart mobility, climate resilience, digital urban planning); small-scale pilot projects demonstrating OD value; citizen feedback mechanisms (surveys, online platforms).

Partnerships: public-private collaborations sharing expertise and resources; regional cooperation between cities and their wider metropolitan areas on the open data agenda.

Common challenges: lack of awareness or technical expertise; absence of a holistic sensor deployment model; inconsistent formats and incomplete datasets; political or bureaucratic resistance to data sharing; and ensuring long-term platform sustainability.



6. The future of Open Data in the Pilot Area - Steps for Implementation

A forward-looking vision for Open Data in the pilot area involves embedding data-driven practices into the fabric of urban governance and community life of each pilot area. This vision recognizes the transformative potential of Open Data to address complex urban challenges, foster innovation, and enhance citizen engagement.

i. Short-Term Goals (Implemented within EnCLOD):

Build stakeholder capacity, launch basic OD platforms with traffic and environment pilot data, improve data quality, engage community through participatory tools, and establish initial partnerships.

ii. Long-Term Goals (Wider Municipality strategy):

Support transition towards fully digital governance where OD and IoT are central; position IoT open data as a stable foundation for digital services (e.g. frost prediction, traffic models) and AI-driven analytics; leverage OD to support the Green Deal agenda; and foster a participatory culture of citizen contribution to OD.

iii. Key enablers

Supportive policy frameworks; ongoing capacity building; technological innovation (interoperability, scalability, AI); sustainable funding models (public-private partnerships, EU grants); and linking OD to Green Deal investment projects (green-digital twinning).

iv. Measuring Success

Key Performance Indicators (KPIs): dataset availability, citizen and stakeholder engagement levels, number of digital services/tools developed, and tangible economic or environmental benefits. Continuous feedback loops should iteratively refine the OD strategy.

This integrated strategy aims to build a robust Open Data ecosystem, driving innovation, strengthening trust, and fostering engagement among all stakeholders. By addressing existing gaps and leveraging opportunities, the pilot area can become a model for sustainable, data-driven urban governance.



7. Part II - Cross-pilot evidence

The following sections synthesise the practical experience gathered from the EnCLOD Pilot Actions, drawing on structured inputs provided by all project partners responsible for pilot implementation. Each thematic section presents consolidated findings across pilot areas, illustrating how the guidelines framework was tested, adapted, and refined in real territorial contexts.

7.1 Pilot Overview

The EnCLOD project implemented Pilot Actions in five territories across Central Europe, each addressing a distinct policy domain within the common framework.

Nova Gorica (PP7 MONG + PP8 UL) focused on mobility and air quality, deploying a combined traffic and environmental sensor network in the context of the city's preparation for the European Capital of Culture year.

Debrecen (PP3 DKV) tackled mobility and public transport planning, deploying traffic sensors around "rapidly developing industrial parks" to create travel patterns and support the design of new, "data approved" public transport services aimed at decreasing private car usage.

Province of Vicenza (LP ProVI + PP2 IUAV) addressed road safety, deploying weather stations along mountain roads to monitor road surface conditions and support winter maintenance operations, specifically "to assess the salt spreading works on the roads during winter."

Olomouc (PP4 CITIQ + PP5 UPOL + PP6 CityOne) focused on heat islands and parking, building the project's most advanced pilot as a "frontrunner, so an advanced concept providing inspiration to the others," combining traffic and climate sensing with a holistic microzoning framework for the entire city.

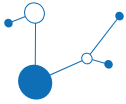
Zilina (PP9 UNIZA) addressed mobility and traffic safety, expanding an existing Urban Living Lab by deploying 42 new sensors at "busy intersections and school zones" to provide data for the development of a planned "Traffic safety preventivist tool." The Zilina pilot capitalised on infrastructure from multiple projects (CleverNet, NXTLVL, and EnCLOD), "delivering high value for money through the sharing of data resources and expertise."

All 5 pilots were implemented between 2024 and 2026, with sensor deployments beginning as early as August 2024 (Olomouc) and November 2024 (Debrecen).

7.2 IoT and Data Infrastructure

The five pilot areas deployed a diverse range of IoT sensor technologies, adapted to their specific policy domains and local conditions. Despite this diversity, several common patterns emerged in sensor selection, connectivity, data aggregation, and publication.

Sensor types and scale. The pilots collectively deployed well over 150 sensors across all partners. Nova Gorica installed 24 Telraam S2 traffic sensors and 7 air-quality sensors, complemented by one reference air-quality monitoring station. Debrecen deployed 42 traffic counter sensors (CITIQ magnetometers) at 4 main locations providing geofencing to industrial sites. Vicenza installed "a total of 15 environmental sensors grouped in 4 weather stations (including 4 thermo-hygrometers, 3 infrared sensors, 1 road status ground sensors, 2 pluviometers, 1 snow gauge, and 4 web cams)" along provincial mountain roads. Zilina deployed 42 new traffic sensors across 18 key locations, which were integrated with legacy infrastructure from previous projects (CleverNet and NXTLVL) to form a combined network of 90 traffic monitoring points - the



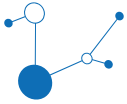
most extensive traffic evidence base in the city's history. Olomouc built the most complex multi-domain infrastructure, combining traffic magnetometers and climate sensors measuring temperature in 5 different levels including -30cm underground, complemented by night parking surveys and portable heat island measurements - with a holistic design that has since been scaled into a public procurement for 338 traffic lanes/sensors and 66 different climate sensors, creating a citywide digital twin for urban planning and territorial governance.

Data streams and aggregation. All pilots generate near-real-time data. A common aggregation interval of 15 minutes was adopted across the project. In Nova Gorica, traffic data is generated in near real time and aggregated in 15-minute intervals, covering multimodal counts and speed estimates, while air-quality sensors provide periodic measurements of PM1, PM2.5, PM10, temperature, humidity, and pressure. Both Debrecen and Zilina provide raw sensor data at 5-minute intervals, while processed traffic data is aggregated at 15-minute intervals for visualization. Vicenza's weather stations generate environmental data in near real time and aggregated in 15-minute intervals, gathered and transmitted by a datalogger. Olomouc adopted the same standard, noting that "15min data seems to be a future standard (as 15min energy trading).

Connectivity models. The pilots demonstrate that no single connectivity solution fits all contexts - the right choice depends on local infrastructure, terrain, and institutional arrangements. Nova Gorica used a hybrid connectivity model: Telraam sensors transmit data via built-in cellular IoT, while environmental sensors rely on LoRaWAN gateways. Debrecen leveraged an existing city-owned network, cooperating with DVU Ltd, (Debrecen's City Operator Company) which already operates a city-wide LoRaWAN gateway network on municipally owned properties. Vicenza, operating in a mountainous and remote area, adopted a connectivity model based on the mobile phone network: NarrowBand-IoT SIM Cards transmit the collected data of the 4 stations. Zilina uses LoRa connectivity as a dedicated wireless network for data transmission, building on infrastructure already established through the Urban Living Lab. Olomouc's recommendation is pragmatic: check connectivity alternatives to pick a right one, or do not prescribe connectivity and let the operators handle it by themselves.

Data storage and publication platforms. Each pilot publishes data through dedicated platforms, with varying degrees of integration into broader open data ecosystems. Nova Gorica publishes traffic data via the Telraam portal and open API (JSON/CSV), and air-quality data available through an open dashboard and exportable formats (CSV). Debrecen uses the project's dedicated analytical interface developed by CITIQ, complemented by a microzoning web application created by UPOL. Vicenza publishes through "a dedicated web platform (called MINA) with dashboard and map visualisations, complemented by publication on "Open Data Veneto, the institutional web portal of the Venetian Region. Zilina publishes all datasets through "the project's dedicated monitoring interface at doprava.digital, which serves as the central hub for all project-related datasets," while work is ongoing to integrate the Urban Living Lab data into the city's Open Data portal via the municipal INVIPO platform (Smart Zilina). Olomouc achieved the deepest integration, publishing sensor data on both "the national open data portal and Olomouc region data portal, becoming the second city in Czech Republic (after Prague) to provide such open data. The Olomouc partners also designed a common landing page for all the sensor data from all the pilot areas, enabling cross-pilot data access and reuse.

Interoperability. Across all pilots, interoperability challenges were reported as manageable, largely because standardised formats and established APIs were used from the outset. Nova Gorica reported that interoperability challenges were minimal due to the use of standardized data structures and APIs, enabling straightforward reuse and integration into municipal and project-level Open Data workflows. Zilina ensured interoperability by adhering to the National Concept of Public Administration Informatization and official IT standards of the Slovak Republic. The consistent adoption of CSV, JSON, and API-based publication across all five pilots supports the conclusion that early standardisation prevents major integration barriers.



Guidelines for IoT and data infrastructure deployment:

Start with a holistic design, not individual sensors. Before deploying any hardware, map the entire territory through microzoning - dividing the city into spatial reference units aligned with existing statistical or census boundaries. Design the sensor network as a complete logical model covering the full territory, then prioritise deployment by policy relevance and budget. This prevents ad hoc placement and creates a scalable foundation for a future digital twin.

Define microzone boundaries by movement, not only by statistics. Basic settlement or census units are the right foundation, but they were drawn for statistical purposes and often no longer match the actual heterogeneity of the territory. The criteria applied in Olomouc and subsequently transferred to the other pilot areas were: keep the number of zones proportionate to the cost of instrumenting them; avoid zones with negligible resident populations; run boundaries along trunk roads, rivers, railways and other linear barriers; account for every access route so that traffic geofencing is achievable with the minimum number of detectors; consider the dominant land use in terms of traffic generation; and preserve the homogeneous character of built-up areas. Applying these rules produced seven zone types - rural single-family residential, mixed-use residential, historic centre, shopping centres, mixed-use, mixed-use planned new neighbourhoods, and industrial areas - plus two special cases, the hospital campus and the university campus, and divided the city into 63 zones covering its entire territory. Expect to split a single settlement unit where a major road runs through it, and to merge several where they form one compact residential district. Where deviation from administrative boundaries complicates the link to statistical data, aggregate from elementary inputs such as address points or satellite-derived surface temperatures instead.

Select sensor technology based on the policy question, not the technology itself. Traffic magnetometers (Debrecen, Zilina, Olomouc) offer privacy-by-design since they detect vehicles without imaging. Camera-based counters such as Telraam (Nova Gorica) provide multimodal classification including pedestrians and cyclists but require careful placement and local video processing to ensure GDPR compliance. Environmental sensor stations (Vicenza, Olomouc) should be specified according to the parameters actually needed by the local policy context - road surface temperature for winter maintenance, air quality for health and mobility planning, or multi-level ground temperature for heat island analysis.

Adopt 15-minute aggregation as the minimum standard. All five pilots converged on this interval, which is granular enough for traffic and climate analysis, compatible with emerging energy trading standards, and manageable in terms of data volume and storage.

Choose connectivity pragmatically. No single solution fits all contexts. LoRaWAN works well where city-owned gateway networks already exist (Debrecen, Zilina). Cellular IoT and NarrowBand-IoT are effective for dispersed or remote locations without existing infrastructure (Vicenza, Nova Gorica). Hybrid models combining multiple technologies within the same pilot (Nova Gorica) offer flexibility. Where possible, do not prescribe the connectivity technology in procurement - let operators propose the most efficient solution for the local context.

Bundle hardware and data services in procurement. All pilots financed deployment through a model that combines sensor hardware with data-as-a-service delivery - including connectivity, dashboards, API access, and open data publication. This reduces the technical maintenance burden on the municipality. Require open formats, API access, structured metadata, and open licences as mandatory procurement criteria from the outset.

Plan for the sensor lifecycle from day one. Zilina's experience integrating sensors from three successive projects (CleverNet, NXTLVL, EnCLOD) highlights that sensor networks evolve over time: hardware ages, roads are reconstructed, monitoring needs shift. Build contractual flexibility for sensor relocation, replacement of legacy units, and network expansion into the initial procurement. Protect sensors from damage during routine street maintenance and winter operations.



***Publish data through multiple channels.** The most effective pilots combined a dedicated project dashboard for real-time visualisation with publication on established regional or national open data portals (Open Data Veneto in Vicenza, the Czech national portal and DATAOK in Olomouc) and direct API access for developers. Early, visible publication - even before the full network is operational - builds momentum and demonstrates value to stakeholders.*

***Complement the sensor network with structured manual surveys.** Sensors cannot cover everything, and some of the most decision-relevant evidence is still collected by people. Two protocols were standardised on the basis of the Olomouc pilot and are directly reusable. The nighttime parking survey records, per street or per street section of roughly 400 m, the total number of parked vehicles, the number parked illegally, the number of vans, the number of electric or hybrid vehicles, and the number of bicycle racks, spaces and parked bicycles; it must be conducted mid-week, at least one day after a weekend or public holiday, in April or May or in September or October, so that the counts are comparable between years and between cities. The nighttime heat island survey maps a fixed route of measurement points, records each point for at least five minutes with readings every minute so that the portable instrument stabilises, and compares the averaged values against the nearest fixed weather station. Daytime heat measurements are not recommended for digital twin purposes because traffic, pedestrians and moving shade introduce too many confounders. Both protocols produce values that can be recalculated to microzones and compared across zones, cities and years, and both feed the calculated indices that give sensor data its planning value.*

7.3 Open Data Outputs

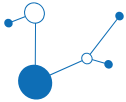
All five pilots published fully open datasets under open licences ensuring free reuse. Nova Gorica provides traffic and air-quality data via the Telraam platform and API, providing hourly aggregated multimodal counts and speed indicators alongside environmental data through an open dashboard with export functionality. Debrecen publishes fully open traffic and environmental datasets under Open Data commons licence through a CITIQ dashboard showing total and hourly numbers of entries and exits, average daily numbers of vehicles by category and the average speed of vehicles. Vicenza publishes through three parallel channels: a dedicated MINA platform with near-real-time updates, Open Data Veneto, the institutional web portal of the Venetian Region with static quarterly uploads, and the Province's own website with a 15-minute update cycle. Zilina publishes all datasets through the project's dedicated monitoring interface at doprava.digital, including multimodal vehicle counts, speed indicators, and vehicle categorization, with ongoing integration into the municipal Smart Zilina portal. Olomouc achieved the deepest publication ecosystem, with data on the national open data portal and Olomouc region data portal - complemented by a dedicated heat island web tool, an ArcGIS microzoning dashboard, and over 150 potential datasets from national, regional, municipal and international providers identified as relevant for the analytical framework.

Guidelines for Open Data publication

***Treat openness as the default, not the exception.** All sensor-generated datasets should be published under standard open licences from the outset. The decision to open data should not require separate justification - rather, any restriction on access should be the exception that needs to be argued. Traffic and environmental data carry no personal data concerns and should be open by design.*

***Publish structured metadata alongside every dataset.** Each published dataset should include clear descriptions of what is measured, the sensor type and location, the measurement interval, the unit of measurement, the coordinate reference system, and the licence. Without metadata, even high-quality data becomes difficult to discover, interpret, and reuse by third parties.*

***Publish on established portals, not only project platforms.** Dedicated project dashboards are essential for real-time visualisation and stakeholder engagement, but they are not sufficient for long-term*



discoverability. Data should also be registered on regional or national open data portals (such as Open Data Veneto or the Czech national catalogue) to reach a broader audience and ensure institutional visibility. Where municipal open data portals exist, integration into these platforms should be planned from the start.

***Understand the three tiers of the publication chain.** Publication is a chain rather than a single act: local catalogue, national catalogue, European portal. Local catalogues are where data is first published and where the publisher retains control; ArcGIS Hub and CKAN dominate in practice, with ArcGIS Hub prevalent among institutions publishing primarily spatial data, and DKAN, Socrata, JKAN, OpenDataSoft and Dataverse also in use. National catalogues aggregate the local ones and give the data institutional standing: the Czech National Open Data Catalogue (data.gov.cz), established in 2015 and administered by the Ministry of the Interior, has a statutory basis in the Act on Free Access to Information and accepts either direct dataset registration or the harvesting of a local catalogue. The European Data Portal (data.europa.eu), built on CKAN and applying CC BY 4.0 unless stated otherwise, then harvests the national catalogues; it stores metadata only and redirects users to the source, which is why metadata quality at the local tier determines discoverability at the European tier. A municipality that publishes only to its own project dashboard remains invisible at both upper tiers.*

***Maintain continuous, near-real-time updates.** Static, periodic data uploads have limited value for operational governance. All five pilots demonstrated that 15-minute update intervals are feasible and provide the granularity needed for traffic, climate, and environmental decision-making. Where platform constraints require static uploads (as in Vicenza's regional portal), these should complement - not replace - the live data stream.*

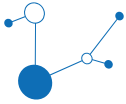
***Provide multiple access formats for different users.** Policy makers and citizens need dashboards and map-based visualisations. Researchers and developers need API access and downloadable datasets in standard formats (CSV, JSON). Procurement specifications should require both: visual presentation for public engagement and machine-readable access for technical reuse.*

***Build the open data layer incrementally.** Start by publishing the datasets generated directly by the pilot sensors, then progressively integrate existing open data from other sources - national statistics, cadastral data, environmental agencies, satellite services - into a unified analytical framework. Olomouc's approach of aggregating over 150 external datasets into a microzoning dashboard illustrates how a pilot can evolve into a comprehensive territorial evidence base.*

***Use visible publication as a stakeholder engagement tool.** Making data publicly available is itself an engagement act. Vicenza's experience shows that "diffusion through social media and a local newspaper article brought them to the attention of the citizens" in the first days of publication. Early, visible publication creates public awareness, invites feedback, and generates demand for further data and tools.*

7.4 Governance and Policy

All five pilots were financed through Interreg CE EnCLOD funds and implemented through partnerships between municipalities, universities, and technical partners. Governance models varied but shared a common principle: treating sensor outputs as a public good. In Nova Gorica, a clear governance choice was made to treat the sensor outputs as a public good, with the municipality committing to adopt a strategic document (Air quality plan) that will dictate the continued use, maintenance, and governance of sensors and Open Data beyond the end of the EnCLOD project. Debrecen embedded the pilot within broader city initiatives, linking EnCLOD data to an Environmental Monitoring System financed by the city, data collecting, analyzing, accrediting is provided by the University of Debrecen, and offering data to the planned City Traffic Management Centre. Vicenza involved its road management company Vi.abilita, which made the commitment to maintain the weather stations beyond the project conclusion and integrate them in a control



room including traffic sensors which is being built. Zilina aligned the pilot with the city's Concept for the Development of Public Administration IT and Innovation (KRIT), adopted in 2024, which supports the automated publication of Open Data and the elimination of vendor lock-in, with efforts ongoing to have the KRIT concept formally adopted by the City Council as a binding regulation. The Zilina pilot is also strategically linked to a national programme on digital twins coordinated by the Slovak Ministry of Investments (MIRRI SR). Olomouc achieved the strongest institutional embedding: the city's office of the city architect became the leader of the initiative, and the holistic sensor design was integrated into the city's ITS strategy, leading to a public procurement for a full digital twin of a value of around 800k Euro, with a contract requiring the supplier to deploy and operate the system for 5 years, including open data publishing and supporting actively future hackathons.

Guidelines for governance and policy:

Anchor the Open Data initiative in an existing policy process. The most successful pilots connected sensor deployment to a concrete governance need already on the municipal agenda - a parking regulation extension (Olomouc), a sustainable mobility plan (Debrecen), a road safety programme (Zilina, Vicenza), or an air quality strategy (Nova Gorica). This creates institutional ownership and political support that standalone technology projects rarely achieve.

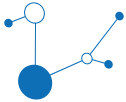
Define data ownership, responsibilities, and continuity before deployment begins. Every pilot should answer three questions at the outset: Who owns the data? Who is responsible for operation, quality assurance, and publication? And how will continuity be financed after the initial funding period ends? These decisions should be documented in a formal governance framework - whether a municipal strategy, a council resolution, or a contractual obligation in the procurement.

Treat IoT outputs as a public good by institutional decision. This was a shared principle across all five pilots and should be formalised rather than assumed. A municipal decision or strategic document explicitly declaring sensor data as openly accessible public infrastructure creates a lasting institutional anchor that survives changes in political leadership or project staff.

Build sustainability into the funding model from day one. Post-project continuity was secured most effectively where pilots planned it early: Vicenza secured a commitment from its road management company to maintain the stations; Olomouc embedded the sensor network into a five-year public procurement contract. Relying solely on project funding without a transition plan is the single most common reason why pilot infrastructures collapse after project closure.

Use procurement as a governance instrument. Public procurement specifications should embed open data obligations as contractual requirements - not optional deliverables. This includes mandatory open formats, API access, metadata, open licences, data quality monitoring, and, where possible, active support for hackathons and community engagement. The Data-as-a-Service model, used across multiple pilots (Zilina, Debrecen, Olomouc, Vicenza), is particularly effective: it shifts the municipal focus from hardware ownership to data delivery, reducing technical burden while ensuring service continuity.

Specify the data service, not only the hardware. The most detailed procurement language produced by the project treats the supplier as the operator of a data service under five standing obligations: deployment and operation of the traffic and climate sensors; publication of the data on the municipal open data portal and in the national catalogue; presentation of the data through dashboards on a publicly accessible web portal; provision of live open sensor data to third parties for the whole operating period; and active participation in the city's hackathons, including data support and mentoring for participants. Around these, require a central database with a documented REST API conforming to a recognised specification such as OpenAPI; temporal and spatial aggregation tools (interval averages, daily statistics, aggregation by location or sensor); export to common GIS formats - GeoPackage, GeoJSON or File Geodatabase - so that data lands directly in the municipal GIS environment; a device registry exportable to the regional digital technical map, recording replacements, repairs and preventive maintenance over time; device status monitoring that



notifies subscribers and the public when devices fail; a help desk for data subscribers with a record of their requests; and a short annual report on the quantitative and qualitative performance of the system. One requirement deserves particular emphasis: bind the published series to logical elements rather than to physical devices. A traffic profile is composed of N detectors and a climate point of N detectors, so that a failed or replaced unit does not break the time series - which is otherwise the most common cause of unusable long-term monitoring data.

Write the dashboard and acceptance requirements into the contract. Dashboards should be specified rather than left to the supplier's discretion. Require a short definition of each metric and its unit; text boxes showing current values, key performance indicators and alerts; interactive charts of appropriate type with labelled axes, units, legends, zoom and tooltips; a map showing sensor locations with a legible legend, sound cartography and interactive points that open sensor detail on click; the logos of the client, the project and, where relevant, the funder; and all labels, buttons and functions in the local language. Add data download in CSV, JSON or XLSX directly from the dashboard, iframe embedding that works without login, HTTPS-secured server-to-server transfer from a fixed IP address, integration with the client's own database by direct connection or defined API, and full responsiveness across desktop, tablet and phone. Established tools such as ArcGIS Online, Grafana or Apache Superset meet these requirements without bespoke development. Finally, set two dates rather than one: the date of handover and activation of the complete network and its dashboards, and a verification window of around fourteen calendar days in which the client inspects compliance with the specification and the supplier is contractually obliged to cooperate.

Eliminate vendor lock-in through open standards. Zilina's KRIT framework explicitly targets the elimination of vendor lock-in as a governance priority. Procurement criteria should require open data formats, documented APIs, and portability of datasets to alternative platforms. This protects the municipality's long-term flexibility and ensures that data remains accessible regardless of future supplier changes.

Align local pilots with regional and national digital strategies. Zilina's link to the Slovak national programme on digital twins and Debrecen's connection to the city's Environmental Monitoring System and planned Traffic Management Centre illustrate how local pilots gain political weight and funding leverage when aligned with higher-level digital governance agendas. Where such national or regional programmes exist, local OD initiatives should actively seek alignment and co-funding opportunities.

Assign clear institutional leadership. In Olomouc, the office of the city architect became the institutional leader of the open data and digital twin initiative, supported by both city and regional open data portals. A designated institutional champion - whether a department, an office, or a named role - is essential for coordinating across municipal agendas, maintaining political visibility, and ensuring continuity.

7.5 Stakeholder and citizen engagement

All five pilots implemented structured engagement programmes combining capacity-building, public events, and co-creation activities. Hackathons were a central element across the project. Olomouc held one with 51 participants attending the event, with 30 active competitors forming 10 teams working over three days at the Envelopa Hub of Palacky University, producing winning projects on road infrastructure monitoring, road surface amortisation modelling, and AI-based weather summarisation. The hackathon was preceded by a dedicated preparatory workshop three weeks earlier to ensure participants understood both the data and the urban context - a well respected urbanist from Prague gave a lecture on good and bad city urbanism and relations to the heat island topic. Nova Gorica organised a dedicated hackathon (SMART City HACK challenge, 16 October) focused on reusing the newly published traffic and air-quality datasets for new use cases and prototypes, which identified the need to create a municipal Open Data portal. Zilina planned a hackathon titled Smoothly through the city, safely home for March 2026, building on earlier engagement



including the international conference DIM 2024 - Transport Infrastructure in Cities: Smart Solutions attended by over 120 participants from Slovakia and the Czech Republic. Debrecen planned its hackathon in cooperation with the University of Debrecen, with which an MOU has been signed, that frames the devotion of the partners and event challenges requiring the usage of the published project data sets. Vicenza planned a hackathon for June 2026 organized in a venue of the University of Vicenza with the support of Vicenza Innovation Hub.

Training and capacity-building activities were delivered across all pilots. Debrecen organised three distinct events: an inspirational workshop in April 2025 with the participation of 40 experts from 5 countries, a mini conference in November 2025 on Best practices of Open Data and usage of data based decision making in Debrecen, and a dedicated Open Data training in December 2025 delivered by lecturers from the Faculty of Informatics of the University of Debrecen. Zilina held a specialised seminar Municipal Open Data Step-by-Step and a Municipal Data Forum workshop, involving 25 participants representing the Municipality of Zilina, MIRRI SR, and regional transport authorities. Nova Gorica conducted several educational workshops in 2025 to introduce IoT and Open Data to municipal staff, local stakeholders, and later students, alongside direct outreach to private hosts of indoor sensors. Vicenza combined a public event Open data at the service of the territory gathering 40 participants from the targeted categories with a training session for 24 participants from the local public administrations. Olomouc held two stakeholder events (November 2024, June 2025) to introduce open data and IoT, both recorded and published online alongside all presentation materials.

Media visibility accompanied engagement efforts in several pilots. Olomouc achieved national coverage through Czech Television (three separate broadcasts), Czech Radio, and multiple regional outlets. Vicenza reached citizens through social media and a local newspaper article in the first days of data publication. Zilina published results through Ekomagazin and participated in the European Researchers' Night.

Guidelines for stakeholder and citizen engagement

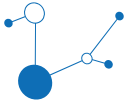
Design engagement as a structural component, not an add-on. Stakeholder engagement should be planned and budgeted from the project's outset, with a clear sequence: awareness-raising events early on, capacity-building workshops during deployment, and co-creation activities (hackathons) once data is available. Treating engagement as an afterthought produces lower participation and weaker institutional ownership.

Make hackathons data-compulsory. The most productive hackathons across EnCLOD required participants to use the pilot's own published open datasets as a mandatory condition. This ensures that outcomes are directly relevant to the local context and that the data is genuinely tested under real use conditions. Olomouc's approach of making data use "a compulsory condition for the hackathoners" produced solutions directly applicable to municipal governance.

Prepare participants before the hackathon. Technical data alone is not enough. Olomouc's model of holding a dedicated educational workshop three weeks before the hackathon - covering both the urban policy context and the available data - resulted in higher-quality submissions. Participants who understand why the data matters, not just what it contains, produce more relevant solutions.

Involve universities as co-organisers. In all five pilots, local universities played a central role in hackathon organisation, training delivery, and technical support. Debrecen formalised this through an MOU with the University of Debrecen; Olomouc worked closely with Palacky University (UPOL); Zilina built on the University of Zilina's (UNIZA) established position in transport research. Universities provide venues, student participants, technical mentors, and institutional continuity that one-off project events cannot sustain.

Layer engagement activities for different audiences. Not all stakeholders need the same format. Municipal staff benefit from focused, practical training sessions (Zilina's "Municipal Open Data Step-by-



Step," Debrecen's dedicated Open Data training). Decision-makers respond to inspirational events with cross-national peer exchange (Debrecen's workshop with 40 experts from 5 countries). The general public is reached through media coverage, social media, and public events tied to visible outputs. The most effective pilots combined all three layers.

***Engage sensor hosts and affected communities directly.** Nova Gorica's experience of conducting direct outreach to private hosts of indoor sensors to build acceptance and gather informal feedback highlights an often-overlooked stakeholder group. Where sensors are placed in or on private buildings, shops, or institutions, building a relationship with hosts increases cooperation, reduces the risk of sensor removal, and creates local ambassadors for the initiative.*

***Record and publish everything.** Olomouc's practice of recording all events and publishing them online alongside presentation materials extends the reach of engagement activities far beyond the room. This is particularly valuable for smaller municipalities where not all relevant officers can attend in person, and creates a reusable knowledge base for future capacity-building.*

***Use media strategically to create public demand.** Publication of open data and sensor results generates newsworthy stories - children breathing warmer air due to heat islands (Olomouc), real-time road conditions on mountain passes (Vicenza), traffic patterns around industrial zones (Debrecen). Proactive media engagement turns technical outputs into public narratives that build political support and citizen interest in continued investment.*

***Plan for continuity beyond project-funded events.** The most sustainable engagement models embed hackathons and training into institutional calendars. Olomouc's public procurement for the digital twin requires the supplier to "actively support" future hackathons for the full five-year operation period. Annual hackathons co-organised with local universities create a recurring cycle of data reuse, tool development, and community building that outlasts individual projects.*

7.6 Results and Impact

Each pilot delivered a functioning, publicly accessible monitoring infrastructure generating continuous open datasets. Nova Gorica created the city's first integrated evidence base to link traffic patterns with air-quality conditions, with hackathon participants turning datasets into prototypes such as dashboards, alerts, and decision-support tools. Debrecen's data shows which modes of transport travelers choose, enabling the estimation of the number of potential public transport users and feeding directly into the planned City Traffic Management Centre. Vicenza's data is being used to assess the works carried out for preventing ice formation on the road during the winter season, verifying the coherence of the works with the road status, providing an innovative tool to the road managing company. Zilina established the most comprehensive traffic evidence base in the city's history, forming the foundation for the planned Traffic Safety Index and high-risk location rankings. Olomouc produced the strongest systemic impact: the pilot led directly to a public procurement for a full-scale digital twin worth approximately 800,000 Euro, with publication on both the national and regional open data portals, national media coverage including three Czech Television broadcasts, a peer-reviewed article in the International Journal of Digital Earth, and a heat island monitoring tool used both for citizen awareness and governance decision-making.

Guidelines for maximising impact

***Connect data outputs to concrete governance decisions.** Open data gains institutional value when it visibly informs a specific decision - a new bus service (Debrecen), a winter maintenance contract review (Vicenza), a parking regulation reform (Olomouc), or an air quality plan (Nova Gorica). Abstract "data availability" is less persuasive to decision-makers than a concrete example of data changing an outcome.*



Use hackathon outputs as proof of concept. Hackathon prototypes - dashboards, alert systems, analytical tools - demonstrate to decision-makers what can be built with the published data, at minimal cost and within days. These prototypes lower the barrier for commissioning full-scale digital tools and services.

Seek academic validation alongside practical outputs. Peer-reviewed publications (as in Olomouc) and documented methodologies strengthen the credibility and transferability of pilot results, and help attract further research funding and cross-project collaboration.

Leverage media coverage to build political capital. Visible public impact - television reports, newspaper articles, social media engagement - translates technical results into political support for continued and expanded investment in open data infrastructure.

7.7 Challenges

Challenges fell into three recurring categories. **Organisationally**, securing permissions and suitable locations was consistently time-consuming - Nova Gorica had to replace planned sites when views were obstructed, Debrecen needed approval from two different authorities for roads shared between municipality and state, and Vicenza found that public procurement in a market that in some countries is still not mature can incur in delays. On data quality, Nova Gorica deliberately used low-cost sensors to maximise spatial coverage, which requires careful placement and ongoing verification/calibration, while Debrecen concluded that operation of sensory network requires well-prepared, experienced professionals. Privacy was addressed by design: all pilots used solutions that publish only anonymised aggregates, with traffic and climate data confirmed as "100% etic and open by default, no GDPR needed." The strongest success factor was team quality - Olomouc attributed results to a well managed and well experienced team, while Zilina achieved high value for money through the sharing of data resources and expertise across multiple projects.

Guidelines for overcoming challenges

Budget time for permissions and site negotiation. Every pilot experienced delays related to authorities, building owners, or heritage offices. Include a dedicated coordination phase of several months before installation.

Plan for sensor failure, relocation, and replacement. Hardware malfunctions, roads are reconstructed, sensors are damaged during maintenance. Build contingency locations, maintenance protocols, and contractual flexibility into the deployment from the start.

Balance coverage against quality. Low-cost sensors enable wider coverage but require calibration; certified instruments deliver precision at fewer locations. The right balance depends on the policy question being addressed.

Choose privacy-compliant technologies by design. Magnetometers and locally processed camera systems that publish only anonymised aggregates eliminate GDPR concerns entirely, simplify governance, and build public trust.

Aggregate sensitive data to the zone rather than excluding it. The project confirmed that climate and transport sensor data can be published without restriction, while remote water and energy meter readings constitute personal data and can be opened only in aggregated form. Microzones supply the aggregation unit that makes this possible: consumption reported at zone level is detached from the household while remaining precise enough to plan green transition investment, size distribution network reinforcement, and identify areas of energy or mobility poverty. Rather than treating water and energy as closed domains, negotiate zone-level aggregates with the utilities and with waste collection services, and be prepared to adjust zone boundaries where the utility's own network structure requires it.



Start procurement early and involve technical expertise. The IoT data-as-a-service market is still maturing. Involving a technology partner or scientific advisor in the specification phase reduces procurement risk and delays.

Capitalise on existing infrastructure and previous projects. Inventory what already exists before deploying new hardware. Incremental investment across successive projects produces far more comprehensive infrastructure than any single initiative.

Invest in people, not only hardware. Team quality was the most cited success factor across all pilots. Training staff, building university partnerships, and creating institutional data roles matter more than sensor specifications.

7.7 Consolidated Recommendations based on all partners' inputs

This section distils the cross-cutting recommendations emerging from all five Pilot Actions into a single actionable reference for local and regional administrations seeking to introduce or strengthen Open Data and IoT for territorial governance.

All five pilot partners converged on a remarkably consistent set of recommendations despite working in different countries, institutional settings, and policy domains. Nova Gorica emphasised adopting a clear data governance framework that treats IoT outputs as a public good, defines responsibilities for operation and data publication, and formalises long-term continuity through municipal rules or ordinances. Debrecen stressed that the strategy should focus on establishing a robust framework to guide data use in support of urban governance and sustainability goals. Vicenza highlighted the importance of involving public authorities from the start in the development of sensor networks and open datasets, responding to their specific requests as a good way to engage the public sector. Zilina recommended formal adoption of governance frameworks at the City Council level as binding regulations" and strategic alignment between local pilots and national initiatives particularly those focused on the development of Digital Twins. Olomouc offered the broadest systemic view: present open data agenda as one of the most promising city agendas that can provide benefits to all the other agendas, bringing significant savings in cost, time and personnel.

On data governance

Adopt a formal governance framework that treats IoT sensor outputs as a public good and defines clear responsibilities for data ownership, operation, quality assurance, and publication. This framework should be embedded within existing municipal strategies (smart city plans, SUMPs, climate adaptation strategies) rather than treated as a standalone initiative. Where possible, seek formal adoption at the City Council level as a binding regulation to ensure continuity beyond individual project cycles and changes in political leadership. Explicitly commit to the elimination of vendor lock-in by requiring open standards, documented APIs, and data portability in all institutional and contractual arrangements.

On sensor deployment

Design sensor networks holistically before deploying any hardware. Divide the territory into microzones aligned with existing statistical or census units to create a logical reference model for the entire city, then prioritise deployment by policy relevance and available budget. Combine traffic and environmental monitoring within the same spatial framework to maximise cross-sectoral value from a single infrastructure investment. Use simple, documented placement principles - clear line of sight, appropriate height, minimal obstructions - and publish all sensor locations transparently via a public map to support replication. Plan for the full sensor lifecycle: include contingency locations, maintenance budgets, provisions for relocation when roads are reconstructed, and protection of hardware during winter maintenance operations.



On procurement

Use procurement as a governance instrument by embedding open data obligations as contractual requirements. Bundle hardware deployment with data-as-a-service delivery - including connectivity, dashboards, API access, metadata provision, and open data publication - to reduce the municipal technical burden. Require open formats, API access, structured metadata, and open licences as mandatory criteria. Adopt 15-minute data aggregation as the minimum standard across all sensor types. Where possible, include a contractual obligation for the supplier to actively support local hackathons and community engagement activities for the duration of system operation. Start procurement planning early and involve an established technology partner or scientific advisor in the specification phase, particularly in countries where the IoT data-as-a-service market is still maturing. Evaluate connectivity solutions pragmatically rather than prescribing a specific technology - LoRaWAN, cellular IoT, and NarrowBand-IoT each have advantages depending on local conditions.

On citizen engagement

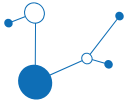
Design engagement as a structural programme, not an add-on. Plan a clear sequence: awareness-raising events during early deployment, capacity-building workshops once data starts flowing, and co-creation hackathons once datasets are mature enough for reuse. Require hackathon participants to use the pilot's own open datasets as a compulsory condition, and precede each hackathon with a preparatory educational event covering both the urban policy context and the available data. Engage sensor hosts and affected communities directly through personal outreach - this builds acceptance, generates informal feedback, and creates local ambassadors for the initiative. Record and publish all events, presentations, and training materials online to extend their reach beyond the room.

On training and capacity building

Invest in building municipal staff competence as a prerequisite for sustainable open data governance. Offer practical, focused training sessions - such as Zilina's "Municipal Open Data Step-by-Step" - that address real operational needs rather than abstract concepts. Complement staff training with cross-national peer exchange events that expose local practitioners to approaches tested in other cities. Involve local university faculties (informatics, geography, urban planning, transport engineering) as training partners - they provide technical depth, institutional continuity, and access to student talent that can be channelled through hackathons and research projects.

On replication and transferability

*The EnCLOD framework is **designed for replication**. Any municipality can begin by selecting a policy entry point, mapping its territory through microzoning, conducting a gap analysis of existing data sources, and defining a governance framework - before purchasing a single sensor. The holistic design approach developed in Olomouc and adapted to all other pilot areas provides a tested methodology that can be transferred to cities of different sizes and institutional contexts. Capitalise on previous and parallel projects by integrating existing sensor infrastructure rather than starting from scratch - Zilina's Urban Living Lab model demonstrates that successive investments compound into a far more comprehensive monitoring system than any single project can achieve. Align local initiatives with regional and national digital strategies (digital twin programmes, national open data portals, Green Deal investment frameworks) to gain political leverage, co-funding opportunities, and broader institutional visibility. Connect sensor deployment to green transition investments, which require data, invest in urban territory, and involve multiple municipal agendas - holistic sensor networks can accelerate these investments while delivering new digital tools at significantly lower cost.*



On standardisation and long-term institutionalisation

Convert pilot experience into a written standard. The strongest guarantee of continuity is not a project report but a specification that outlives the project. EnCLOD results have been drafted into a national-level technical standard for intelligent transportation systems and digital land-use planning, covering microzone design as a reference territorial unit, the open data strategy including dynamic data, the mapping of existing and potential data sources, the requirements to be placed on the public procurement of sensor services, and the user skills needed to operate the resulting system; the same document defined the conditions for the Olomouc digital twin tender. Municipalities that cannot initiate a national standard should still write their own local version - a short, formally adopted document that every future procurement, department and political administration inherits by default. The full structure of that standard - its scope, terminology, strategic activity plan, microzone method, survey protocols and procurement requirements - is synthesised in Annex I.



Annex I - Outstanding example: the technical standard developed from EnCLOD results

Intelligent Transportation Systems - Digital Land-Use Planning - Supporting Territorial Governance Through Open Data on Mobility and Climate

This annex synthesises, in condensed form, the Czech technical standard drafted on the basis of EnCLOD results. Several of its provisions have been woven into Parts I and II of this deliverable as operational guidance; the purpose of this annex is to present the instrument as a whole, so that its internal logic, its evidence base and its status as a project result are visible in one place. The synthesis follows the structure of the source document: rationale, scope, terminology, strategy, conceptual principles, the microzone framework, available data and its uses, and the requirements to be placed on providers of open sensor data services.

A.1 Why this instrument is showcased

Project outputs normally end their life as reports. This one ended as a draft of a technical standard. That is the highest form of capitalisation available to a project of this type: pilot experience converted into a normative instrument that outlives the funding period, that future procurement inherits by default, and that does not depend on the continued presence of the individuals who ran the pilots. It was drafted on the basis of the sensor network deployments in Olomouc and Zilina carried out under EnCLOD, and it defined the conditions for a successful digital twin tender for the city of Olomouc - that is, it was tested against a real procurement before being written down.

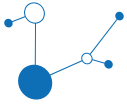
For the other pilot areas the transferable value is not the Czech legal framework, which is national, but the demonstration that a set of pilot lessons can be expressed as a specification with a defined scope, fixed terminology, a reproducible method, a sequenced activity plan and enforceable procurement requirements. Every element of that structure can be reproduced under another legal system, or adopted at municipal level where no national route is available.

A.2 The problem the standard addresses

Investment decisions about land use are being taken under compounding uncertainty: climate impacts, the cost of the green and digital transitions, deglobalisation, artificial intelligence and constrained public budgets. Municipalities now decide on matters that were not on the table a few years ago, and every decision is expected to respect sustainability. The demand for knowledge and information, among both officials and designers, is rising faster than the supply, and few investment projects are actually designed against their spatial, climatic, energy, transport and economic context. Obtaining that information through digitisation is the precondition for decisions and permits that are both well informed and swift, and it is the practical expression of the EU objective of linking the green and digital transitions.

Traditional instruments already exist - in the Czech case the national geoportal for spatial planning, the digital technical map and the national open data catalogue - and they are robust, but they cannot cover everything in a rapidly changing environment. Nor is the constraint a lack of tools: 3D and AI-supported applications capable of visualising options, computing volumes and preparing material for public discussion already exist. What blocks them is the absence of accessible, reliable, current local data, such as heat island values related to parking areas and the traffic these areas generate. The standard's answer is that providing ethical, comprehensive, reasonably accurate, current and open data for spatial planning should itself be treated as a public service, because such data are the building blocks of digital urbanism.

Parking is used throughout the document as the illustrative case, and it is worth reproducing because it shows what data-driven planning is for. Architects once designed parking to serve a building; today they



design buildings to satisfy parking ratios. The result is cities that read as parking lots, with low climate resilience, little green space, and high capital and operating costs carried by the public. Parking policy is in practice one of the most effective instruments for regulating public space, yet without digitisation there is no impact assessment, no credible communication with citizens and no transparency about how parking revenue is used. A rational approach combines incentive and restrictive measures financed through a mobility fund, replaces the unsustainably low cost of resident parking with proven pricing regulation for visitor parking aimed at an occupancy of roughly 85 per cent, and reinvests revenue where it was collected, with the severity of local need measured and compared rather than asserted. The wider ambition follows from this: to replace rigid quantitative development requirements with parameters derived from data.

A.3 Scope: four challenges, five definitions

Many municipalities are already acquiring sensors and technologies in order to monitor phenomena and manage their territory better, but there is no standardised approach to how those steps should be taken, which needs should be monitored technologically, or what knowledge staff require. The standard frames the challenge for local government in four questions: how to identify the right locations and deploy detection technologies so that they yield reliable, ethical and open data; what quality and reliability standards sensors should meet and how the service should be procured; what standards the data should follow and how it should be published as open data; and how digital services should be used in land-use planning.

Against those questions, the standard defines five things:

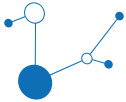
- **Microzones** as reference territorial units for digital urban planning.
- **An open data strategy** that includes dynamic data, for example from the Internet of Things, rather than static registry data alone.
- **A mapping method** for existing and potential open data, based on the technologies, data providers and other partners already present in the territory.
- **Public procurement requirements** for IoT sensors, framed so that the object of the contract is not just the hardware but the provision of a data service to third parties.
- **The user skills** necessary to operate the resulting system.

The standard also names the complex problems that digitisation is expected to help address: the lack of affordable housing and the suburbanisation and commuting it drives; the impacts of climate change and urban heat islands; energy poverty; mobility poverty; water management and drought; sustainable waste management and the circular economy; and, underlying all of them, cross-sectoral cooperation across a wider region. None can be resolved within a single municipal boundary, which is why the standard works at the scale of the functional urban area.

A.4 Terminology fixed by the standard

A standard's first function is to stabilise vocabulary. Ten terms are defined; the following are those that carry methodological weight in this deliverable.

- **City digital twin:** a dynamic virtual model of a real urban area integrating spatial data, real-time sensor data and advanced simulation, serving as a replica for infrastructure management, analysis of phenomena and development planning.
- **Digital urban planning:** a set of digital services combining open data, dynamic IoT data, machine learning and artificial intelligence to support green transition investment planning and the assessment of socioeconomic impacts within a central municipality's functional urban area.



- **Digital transition in urban planning:** a holistic approach to using static open data and deploying sensors for dynamic open data, reflecting the needs of different sectors, territories and investors.
- **Open data:** machine-readable data published on the internet that anyone may freely use at any time without technical or legislative restriction.
- **Microzones:** virtualised territorial units for independent strategic planning using static and dynamic open data, addressing the problem of standardised data collection and interpretation within a universal framework.
- **Geofencing:** zone-based traffic monitoring through the creation of a virtual geographic boundary, typically a microzone.
- **Mobility poverty and energy poverty:** respectively, the inability or limited ability to reach work, school or a doctor because of poor connections, high fare costs or the absence of suitable transport; and the condition of a household unable to meet basic energy needs such as heating, hot water or lighting, driven by low income, high energy prices and poor building efficiency.

A.5 The open data strategy: logic, seven steps and an activity plan

The universal logic of the standard links five elements: the territorial reference framework to which data is attached, that is the microzones; what is already available as open data; what dynamic data is already being collected by technologies, and where, about what and by whom; what survey and questionnaire data exist, including data from mobile applications and emotional mapping; and for what purpose which data are needed, that is use cases and their connection to specific datasets. The role of public administration is to provide forward-looking open datasets as the foundation of the digital transition, to be taken up by commercial entities for various purposes and to fuel new or existing digital tools. Ethics is treated as a design constraint rather than a disclaimer: the project confirmed that sensor data from IoT climate and transport devices can be published freely, whereas water and energy readings are personal data and can be opened only in aggregated form, which is precisely why the definition of the territorial unit is decisive.

Seven steps operationalise that logic:

- **Step 1.** Establish an informal working group and hold a first local event. Outcome: a list of topics important to the municipality that open data could support, an assessment of partnership potential and hackathon content, and a described open data ecosystem.
- **Step 2.** Propose holistic microzoning as virtual land-use planning units, respecting existing statistical units. Outcome: a pilot microzone map.
- **Step 3.** Map all available open datasets, primarily spatial, to those microzones. Outcome: a map of open data by microzone and a comparative analysis of coverage.
- **Step 4.** Map the potential of dynamic data by inventorying every technology already operating in the municipality. Outcome: a registry of potential dynamic data sources with locations, types and providers.
- **Step 5.** Design sensor deployment against that inventory in order to reveal uncovered locations and phenomena. Outcome: a map and table of holistically designed sensors, or a minimum IoT network, quantified with acquisition and operating economics.
- **Step 6.** Organise the first hackathon and build partnerships between data providers and data users. Outcome: hackathon content and a list of the datasets used.
- **Step 7.** Create an action plan for publishing open data on a municipal, regional or national portal, including sensor and survey data, identifying costs and benefits and the commercial digital services that could already use the data. Outcome: published open data that enables more advanced services for more effective land management.



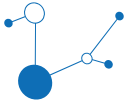
The same sequence is then expressed as a phased action plan in five groups - a preparatory phase run by the municipality with a strategic partner (0.X); data mapping (1.X); territorial division and the data collection plan, with a technical partner (2.X); organisational and networking activities with the identified partners (3.X); and feedback and strategic activities, where appropriate at a higher administrative level (4.X). Table A.1 reproduces the full activity list, which is the element of the standard most directly transferable into a municipal work programme.

ID	Activity	Description and outcome
0.1	Establish an informal city working group	Launch work on the open data ecosystem and describe the system of responsibilities, coordination rules, networking events and the partnership and funding model, as a prerequisite for the open data strategy. Example: the open data strategy prepared for Olomouc by UPOL (2022), including recommendations on working with data, establishing a data portal and organising supporting hackathons.
0.2	Formalise the agenda	Open discussions between the city and its partners, data providers and technology operators, particularly in climate and transport; define challenges and partnerships within the framework of a hackathon.
1.1	National and spatial statistics	A list of national statistical and spatial datasets the city is able to use.
1.2	Local static open data	A list of existing datasets to be used, with an assessment of their timeliness and accuracy.
1.3	Register of potential dynamic data sources	A map of the locations, types and providers of all data-collection technologies already operating in the area, plus a list of potential providers, data types and definitions of dynamic datasets.
1.4	Data providers	Negotiations with IT and ITS system operators on data access, for example from traffic loops at intersection systems, and traffic data from barrier and access control systems at facilities such as hospitals or car parks.
2.1	Microzoning of the city	A holistic microzoning of the municipality for the purpose of defining virtual land-use planning units. Outcome: a map of microzones.
2.2	Mapping of all available open datasets	A list of microzones and the open datasets available for each, a brief comparative analysis of open data coverage in the area, and the creation of initial heat maps.
2.3	Holistic view of transport and climate data collection	A map and table of holistically designed sensor coverage of the city by use case, with specifications for a minimum IoT sensor network.
2.4	Potential of dynamic data against available technologies (see 1.3)	A city strategy and action plan for sensor-covered locations, covering at least climate and transport and including the economics of acquisition and operation, in order to fill previously uncovered locations.
2.5	Aggregation of water and energy data	Verify the feasibility of collecting sensitive data in aggregated form on the basis of the microzone concept from energy and water utilities, and potentially also from waste collection services.
3.1	Internal working group	Open the discussion on open data, sensor data and survey data to a broader professional audience and hold the first local awareness-raising event. Outcome: a set of topics for further exploration and a list of key individuals interested in the agenda.
3.2	List of potential partners	Identify further partnership opportunities in the wider region, align with national or regional strategic objectives, and assess the effect on hackathon content and outcomes, including digital tools already used by other municipalities, internationally where relevant.



ID	Activity	Description and outcome
3.3	Set up a local website	Centralise all information in one place and promote the new site through the media and through partners.
3.4	Open data dashboards	Integrate the available open data into the local website and publish it in the form of a public dashboard.
3.5	Regular events	Organise workshops to introduce the topic and raise awareness.
3.6	Hackathon preparation	Establish partnerships between data providers and data users in order to define challenges for local hackathons. Outcome: content for the first hackathon.
3.7	Hackathon organisation and evaluation	A final report and a list of the available datasets used by hackathon participants.
3.8	Training	Identify key personnel and produce a list of employees to be trained on using open data for more effective territorial management, or on other agendas.
3.9	Training 1	An official workshop for the personnel identified under 3.5 and 3.8, introducing the open data agenda and the potential of digital transformation.
3.10	Training 2 and beyond	Training on the use of existing digital tools to address specific local government priorities.
4.1	Sharing feedback from the collection of use cases	A list of use cases addressing the data-driven needs of local government in specific policy areas, particularly green transition and climate change, identified by participants at awareness events, hackathons or training. They serve both as hackathon challenges and as networking opportunities.
4.2	Sharing feedback on datasets required for specific use cases	Compare participants' suggestions against the availability and necessity of specific datasets, and formulate specific action plan items to secure that data.
4.3	List of digital services and tools	Maintain an up-to-date list on the website (3.3) of services already on the market whose use would streamline the work of the municipality or its affiliated companies, and add a specific action plan item for their implementation, including training.
4.4	Feedback on digital services	Use of digital services leads to their natural improvement; feedback from testers and users should be fed back into the list maintained under 4.3.
4.5	Twinning	Partnerships with local governments working similarly with digital tools for open data, and the sharing of best practice, including suggestions, training and more advanced networking, for example through a relevant association or organisation.
4.6	Development of an open data strategy and action plan	Finalise the strategy on the basis of partner input and discussion. The outcome should ideally be an official municipal open data strategy including a timeline, financial support, an open data publication plan, a strategy for investment in data technology and research, and staffing arrangements including regular training.

Table A.1 - Strategic steps of the open data agenda for territorial governance and urban planning, as set out in the technical standard developed from EnCLOD results.



A.6 Three conceptual principles

The conceptual section of the standard is aimed at overcoming silo mentality, departmentalism and narrowly scoped data collection, so that data is managed as a service for all potential stakeholders and transport data, for instance, becomes usable outside the transport sector. Three principles carry that aim.

Principle 1: use established portals. Publication is a chain rather than a single act. Local catalogues, where data is first published and where the publisher retains control, are dominated in practice by ArcGIS Hub and CKAN, with DKAN, Socrata, JKAN, OpenDataSoft and Dataverse also in use. National catalogues aggregate them and confer institutional standing: the Czech National Open Data Catalogue (data.gov.cz), established in 2015 and administered by the Ministry of the Interior, rests on the Act on Free Access to Information and accepts either direct registration of datasets or harvesting of a local catalogue. The European Data Portal (data.europa.eu), built on CKAN and applying CC BY 4.0 unless stated otherwise, harvests the national catalogues; it holds metadata only and redirects users to the source, which is why metadata quality at the local tier governs discoverability at the European tier.

Principle 2: treat dynamic open data as a public service. Static publication is not enough once data is generated continuously by many providers. The standard cites the Sentilo platform operated by Barcelona City Council as best practice: an open-source sensor and actuator platform running across a sensor estate exceeding 15,000 devices, covering pedestrian and cycle flows, street-level noise, neighbourhood temperature and air quality. Its architecture separates three layers around a single HTTP and REST interface. Providers - devices, hubs and third-party systems, connected directly or through protocol adapters for SCADA and smart metering - publish data and alerts upward and subscribe to orders. The platform layer catalogues every provider, component and sensor with its metadata, stores incoming data in real time, republishes it in standardised form through a publish and subscribe mechanism, runs data processing agents for alerting against quality thresholds, external storage and connectors, and applies security, governance, monitoring and audit across everything passing through it. Applications consume from the same interface, may publish back as virtual sensors, and their use is tracked and audited. The structural consequence is that suppliers can be replaced without breaking applications, and applications added without renegotiating with suppliers.

Principle 3: proceed from the simplest data to the most complex. Data can be ranked by difficulty, acquisition cost and source availability, and should be acquired in that order. The foundational layer is static open data from international, national and other registries - census data, traffic surveys, property inventories, registers of economic entities - which is standardised, long-lived and therefore reliable. Above it sits data generated by technologies, some collected once (satellite imagery, nationwide mobile operator data), some dynamic (remote sensing, aerial and drone imagery, floating car data, existing camera systems and IoT networks delivering near real-time values or long-term statistics), and some available as historical statistics. The most resource-intensive layer is data collected by people: socioeconomic surveys and questionnaires, emotional mapping, community and participatory activity - rare and purpose-specific, and usually meaningless without registry and technology data to give them context. The highest layer consists of values calculated from the three beneath, as indices and coefficients: simple ratios such as parking spaces per dwelling, and more complex ones such as the real-world parking ratio derived from nighttime surveys combined with sensor data, or the greening potential of a parking area derived from occupancy data combined with heat island measurements. Calculated data are described as the breakthrough, because they describe the complexity of urban planning well enough to define territorial boundaries on a new logic and to replace rigid quantitative requirements, such as a fixed proportion of green space, with a qualitatively higher standard of climate-resilient space aimed at thermal comfort and sustainable water management.

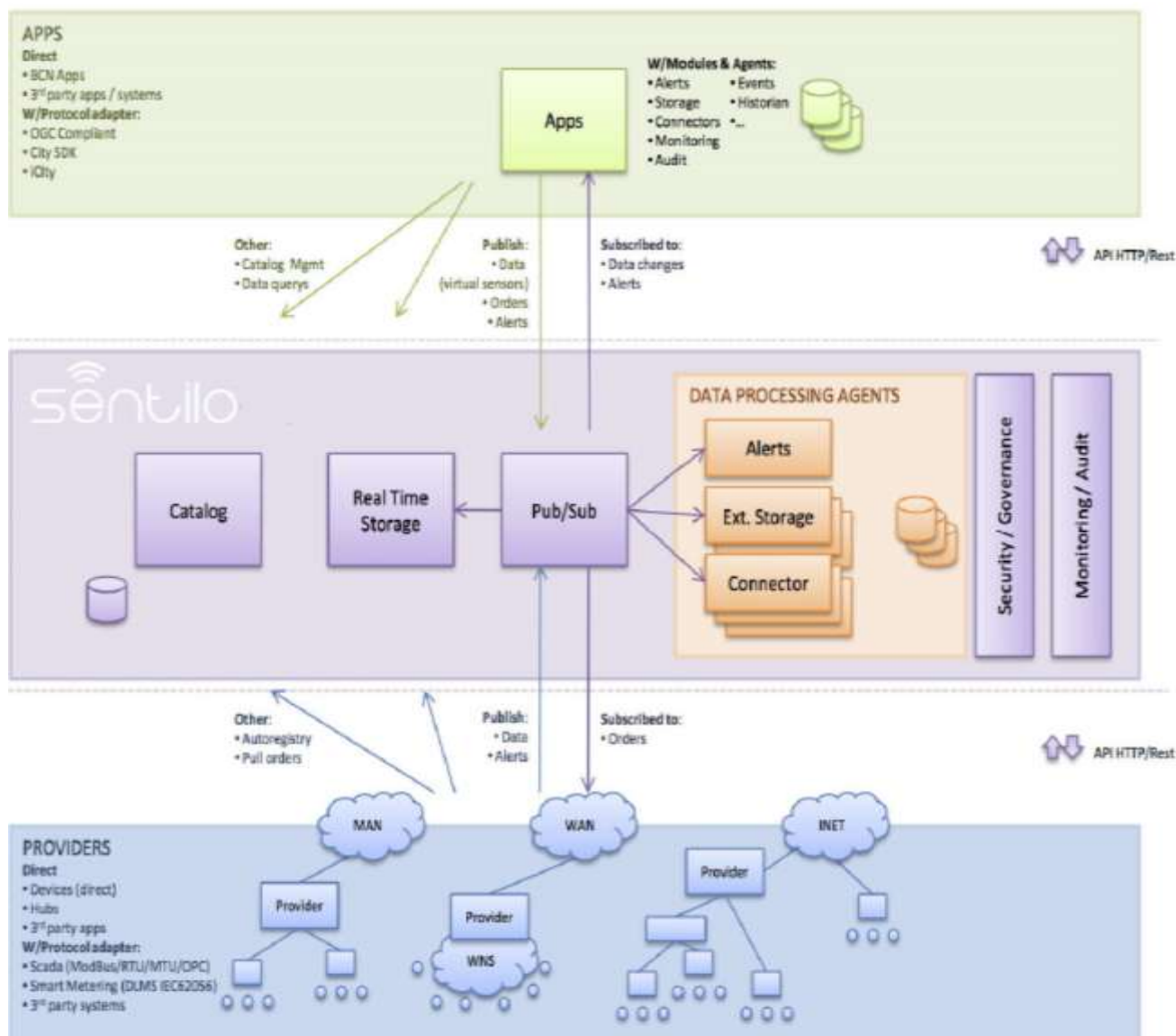
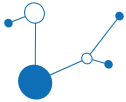


Figure A.1 - Three-layer architecture cited by the standard as best practice for delivering dynamic open data as a public service: providers (lower layer), the platform with its catalogue, real-time storage, publish and subscribe core, data processing agents and security and audit functions (middle layer), and consuming applications (upper layer). Source: Sentilo project documentation, as reproduced in the technical standard developed from EnCLOD results.

A.7 Microzones as the reference framework

Defining microzones is the prerequisite for everything else, because it is what allows sensor, socioeconomic, demographic and other data to be combined into relevant and usable results. The starting point is the existing administrative division, in the Czech case the basic settlement unit, which represents parts of a municipality with distinctive territorial, technical and urban planning conditions. Zones may vary in size, but census units must be respected, ideally with each belonging to a single microzone. Boundaries follow transport logic: rivers and their bridges, railways, trunk roads and other linear obstacles, with neighbouring municipalities treated as separate zones. Climate sensors are then designed holistically so that one device can serve several zones, while traffic detectors are positioned to cover a zone's entrances and exits, achieving traffic geofencing either physically or by calculation from the profiles of collector roads on the



boundary. Microzones also serve as the aggregation unit for sensitive water and energy data, and obtaining that data may itself require the zone design to be adjusted.

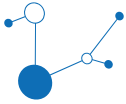
Because urban environments evolve, settlement units no longer always reflect the actual heterogeneity of the territory, so their boundaries are adjusted using local expertise against six criteria: avoid an excessive number of zones, given the cost of installing sensors; avoid residential zones with minimal populations; define boundaries by major transport routes and natural barriers; account for all access routes so that geofencing can be achieved with the minimum number of sensors; consider the predominant land use in terms of traffic intensity; and preserve the homogeneous character of built-up areas such as housing estates, single-family districts and industrial complexes. In practice a single settlement unit is split where a major road runs through it, and several are merged where they form one compact residential district.

Applying these rules produced seven main microzone types - residential rural single-family, mixed-use residential, historic centre, shopping centres, mixed-use, mixed-use planned new neighbourhoods, and industrial areas - together with two special categories, the hospital campus and the university campus. On this basis the pilot city of Olomouc was divided into 63 microzones covering its entire territory. Where deviation from statistical boundaries complicates the link to existing statistics, the problem is generally resolved by aggregating elementary inputs such as address points, or by using geographic data such as satellite-derived surface temperatures. The resulting division is required to satisfy three characteristics: it enables comparison on selected indicators such as population, temperature or traffic volume; it provides a logical basis for designing the IoT sensor network and for integrating survey results; and it enables targeted collection aimed at analytical outputs such as heat maps, supporting research and the development of future applications.

A.8 What the framework makes possible

The first step towards a digital twin is not new hardware but the recalculation of existing open datasets to microzones. Each zone then carries basic datasets derived from available statistics: population, car and bicycle parking capacity, the cycle network, elevation, the quantity and quality of green space, service availability and so on. Combined with the development typology, these support an accurate estimate of current and future traffic volume and parking demand and of the factors driving them, so that the impact of ill-considered construction or of an attractive new facility such as a shopping centre can be calculated before the decision is taken. In the pilot, selected datasets were recalculated for the 63 Olomouc microzones and the exercise was then extended to Zilina, Debrecen and Nova Gorica, demonstrating transferability. This made possible a comparison of the number and type of available datasets, so that each municipality can assess its own level of progress; a comparison of zones across cities, giving a data-driven overview of building typologies and infrastructure; the calculation of initial uniform coefficients such as parking spaces per capita; and, once sensors were installed, comparison of traffic behaviour within zones including nighttime parking - overall volume, average occupancy and parking demand - together with coefficients such as the actual parking ratio per dwelling.

For dynamic data, the standard identifies seven basic use cases: city geofencing, covering transit traffic and traffic from the catchment area with vehicle counts at 15-minute intervals; parking, including residential and housing estate zones, parking coefficients for new development, car-sharing, electromobility and logistics planning, and socioeconomic analysis of traffic load against service availability; commercial zones, hotels and schools, including transport demand, the effect of sales events or new attractors such as outlet malls, and the potential to reduce parking capacity in favour of green space; parking areas, with demand and occupancy at 15-minute intervals supporting flexible demand-based pricing and occupancy-based time regulation; corporate mobility plans, assessing the transport impact of major employers; traffic safety near schools, assessing conditions at crossings against density and speed and setting variable speed limits that flex through the week; and traffic measures generally, from one-way conversions and wrong-way violations to two-way cycle lane planning.



Because many surveys lack a methodological framework and are therefore interpreted inconsistently, the standard also fixes two survey protocols tied to transport areas. The nighttime parking survey works at the level of a street or a street section of roughly 400 m and records the total number of parked vehicles, the number parked illegally, the number of vans, the number of electric or hybrid vehicles, and the number of bicycle racks, spaces and parked bicycles; it must be conducted mid-week, at least one day after a weekend or public holiday, in April or May or in September or October, so that counts are comparable between years and between cities. The nighttime heat island survey maps a fixed route of measurement points, records each point for at least five minutes with readings every minute so that the portable instrument stabilises, and compares averaged values against the nearest fixed weather station; daytime measurement is not recommended for digital twin purposes because traffic, pedestrians and moving shade introduce too many confounders.

A.9 Requirements on providers of open sensor data services

The final substantive section is the one with the most immediate practical value, because it converts everything above into contract language. The provider is treated as the operator of a data service under five obligations: deployment and operation of IoT sensors for traffic and climate monitoring; publication of data on the city's open data portal and in the national open data catalogue; presentation of data through dashboards on a separate, publicly accessible web portal; provision of live open sensor data to third parties throughout the system's operation; and active participation in and support for the city's hackathons for at least the duration of that operation, including data support and consulting for contestants. Sensor data is anonymised by default, and the provider must document the technical parameters of the system including GDPR compliance.

Ten functional requirements follow: unified data collection with incident resolution for connectivity and detection accuracy; data aggregation and transformation into short-term and long-term statistics at 15-minute intervals for traffic profiles, microzones and climate points; online communication through a public website carrying the city's branding; an integration API with a metadata registry and documentation conforming to a standard specification such as OpenAPI; centralised device management with an exportable registry usable by the administrator of the regional digital technical map, recording replacements, repairs and preventive maintenance over time; device status monitoring that notifies subscribers and the public on malfunction; big data support and a help desk tracking subscriber requests, with a maintained list of subscribers, roles and permissions; publication of selected aggregated data as open data in cooperation with the city; reports and statistics, including a public demonstration dashboard and a brief annual report on quantitative and qualitative system performance; and hackathon partnership. One requirement in this list deserves particular emphasis, because it resolves the most common cause of unusable long-term monitoring data: aggregation into logical elements, whereby one traffic profile is composed of N detectors and one climate point of N detectors, so that the physical replacement of a failed sensor does not break the continuity of the series.

Dashboards are specified rather than left to the supplier. Each must carry short definitions of the metrics and their units; text boxes showing current values, key performance indicators and alerts; charts of a type appropriate to time series, distributions and relationships, interactive with zoom, scroll and tooltips, with labelled axes, units and clear legends; and a map visualising sensor locations and their data, with a legible legend, sound cartographic hierarchy and interactive points that open sensor detail on click. Client, project and where applicable provider or funder logos must be displayed, and all text, labels, buttons and functions must be in the local language. Established tools such as ArcGIS Online, Grafana or Apache Superset satisfy these requirements without bespoke development. Beyond content, dashboards must allow download of raw or aggregated data in CSV, JSON or XLSX; embedding of individual charts or dashboard sections in external sites via iframe without requiring the public to log in; server-to-server download over HTTPS; transparent integration with the client's own database by direct connection or defined API; and full responsiveness across desktop, tablet and mobile.



Two provisions close the section and are easily overlooked in procurement. Data flows to the contracting authority's server must originate from a fixed IP address, which may not be changed without prior written consent, so that network rules can be configured and security assured. And the contract should set not one date but two: the date of official handover and activation of the complete, functional sensor network and its dashboards, and a verification deadline - the worked example is 14 calendar days - during which the client inspects compliance with the standard and the other contractual provisions, and during which the supplier is obliged to provide full cooperation and support.

A.10 Status, open items and transferability

Transferability should be assessed at two levels. The legal anchors are national: the Act on Free Access to Information, the National Open Data Catalogue, the digital technical map and the geoportal for spatial planning are Czech instruments, and each partner country would substitute its own. The methodological content is not national. The microzone criteria and typology, the data complexity ladder, the seven steps and the activity plan in Table A.1, the two survey protocols and the requirements on sensor data service providers can all be adopted unchanged, and were in fact already applied beyond the Czech Republic during the project, in Zilina, Debrecen and Nova Gorica. The recommendation that follows for the partnership is therefore twofold: each partner should assess whether a comparable national or regional instrument is achievable in its own system, and where it is not, should adopt the same content as a formally approved municipal standard, which requires no legislative route and delivers most of the same continuity benefit.