Local Digital Twins for Smart Sustainable Communities

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Technical Landscape Report for Pilots

WP2 – Task 2.4

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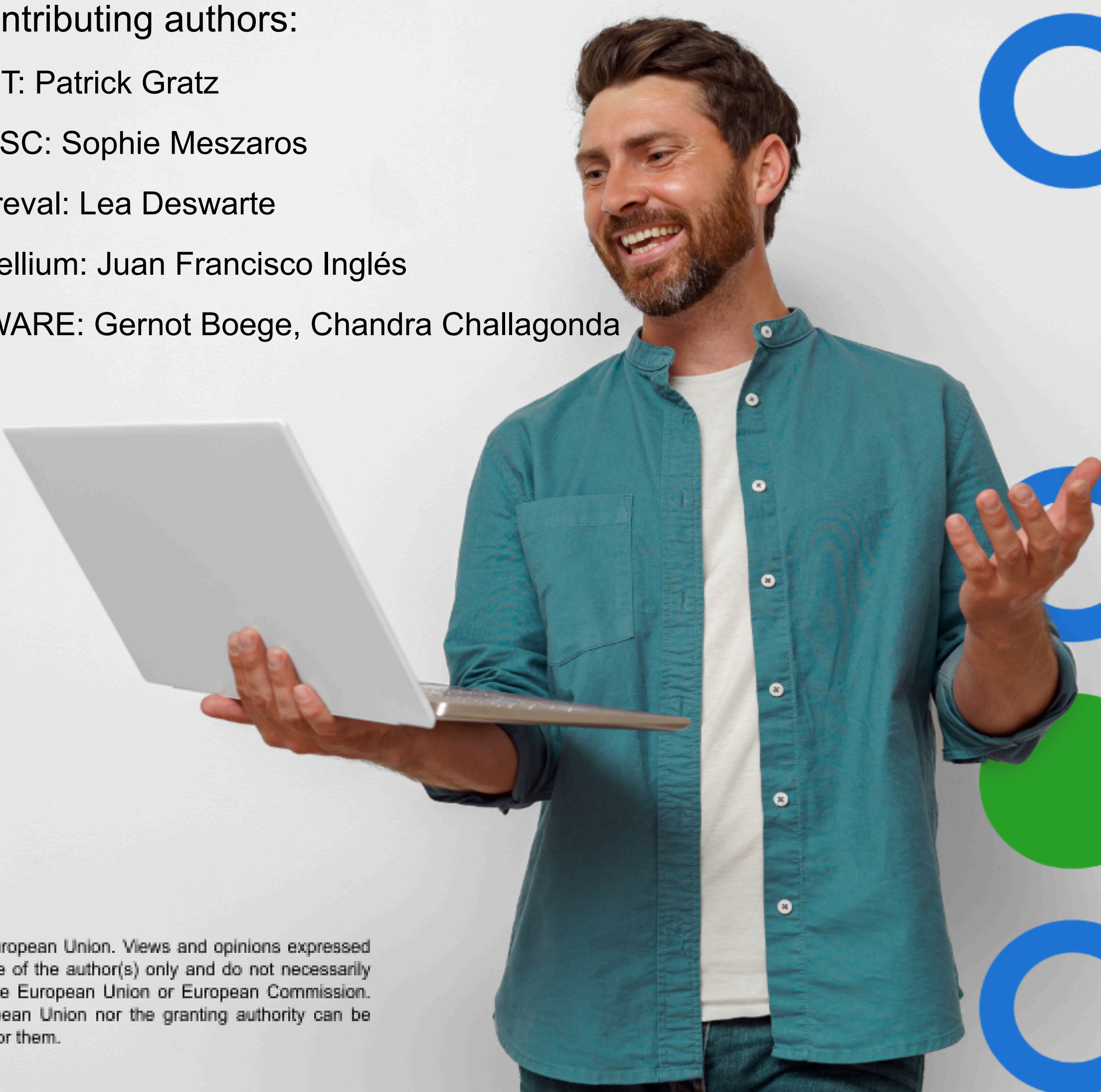

Document information

The Technical Landscape for pilots establishes the technical foundation to help integration of new systems and datasets, linking up to SIMPL, data space connectors, producing relevant technical early-stage recommendations targeting applying and awarded pilots.

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Abbreviations and acronyms

Abbr.	Description	Abbr.	Description
2D	2-Dimensional	JSON-LD	JavaScript Object Notation – Linked Data
3D	3-Dimensional	KPI	Key Performance Indicators
ArcGIS®	Platform of services by Esri Connect people	KServe	Open-source project on Kubernetes
ABAC	Attribute-Based Access Control	LDES	Linked Data Stream Event
AI	Artificial Intelligence	LDS	Language Data Space
AMQTP	Advanced Message Queuing Protocol	LDT	Local Digital Twin
API	Application Programming Interface	LDT4SSC	Local Digital Twins for Smart and Sustainable Communities
AR	Augmented Reality	LDT CitiVERSE EDIC	CitiVerse and the Networked Local Digital Twins towards the CitiVERSE European Digital Infrastructure Consortium
AS4	Applicability Statement 4 (open standard)	LIME tool	Local Interpretable Model-agnostic Explanations
BDTI	Big Data Test Infrastructure	LOST	Legal, Organisational, Semantic, and Technical (EIF layers)
BDVA	Big Data Value Association	MIMs	Minimal Interoperability Mechanisms
BI	Business Intelligence	ML	Machine Learning
BIM	Building Information Modeling	MLflow	Machine Learning flow (open-source platform for ML)
BIM2CityGML	Process of converting BIM data into CityGML format	MLOps	Machine Learning Operations
CA	Consortium Agreement	MoU	Memorandum of Understanding
CAMSS	Common Assessment Method for Standards and Specifications	MQTT	Message Queuing Telemetry Transport
CARLA tool	Car Learning to Act (open-source simulator)	MVP	Minimum Viable Product
CD pipeline	Continuous Delivery/Deployment workflow	NB	Nota Bene (= Remark)
CDS	Common Data Spaces	NGSI-LD	Next Generation Service Interfaces - Linked Data
CEN	European Committee for Standardization	OASC	Open & Agile Smart Cities & Communities
CENELEC	European Committee for Electrotechnical Standardization	OASIS	Organisation for the Advancement of Structured Information Standards

CI pipeline	Continuous Integration workflow	OAuth2	Open Authorisation (framework)
CIM	City Information Modeling	OData	Open Data Protocol
CityGML	Open, standardised data model and exchange format (to store 3D models of cities etc.)	ODbL	Open Database License
CityJSON	Data exchange format (for digital 3D models of cities etc.)	ODI	Open Data Institute
CPSV	Core Public Service Vocabulary	ODRL	Open Digital Rights Language
CRM	Customer Relationship Management	OGC	Open Geospatial Consortium
CRS	Coordinate Reference Systems	OIDC	Open ID Connect
CSV	Comma-separated values	OIDC4VC	OpenID for Verifiable Credentials
CWA	CEN Workshop Agreement	OIDC4VP	OpenID for Verifiable Presentations
DB	Database	OIP	Open Inference Protocol
DCAT	Data Catalog Vocabulary	OLA	Operational Level Agreement
DCAT-AP	Data Catalog Application Profile	OMA	Open Mobile Alliance
DCATv3	Data Catalog Vocabulary Version 3	OPA	Open Policy Agent
DEP	Digital Europe (Work) Programme	OS	Operating System
DID	Decentralised identifiers	OSS	Operations Support Systems
DIGITAL Europe	Digital Europe Programme	OWL	Web Ontology Language
DISP	Data Intermediation Service Provider	PAP	Password Authentication Protocol
DOME	Distributed Open Marketplace for Europe	PDP	Policy Decision Point
DSBA	Data Spaces Business Alliance	PEP	Product Environmental Profile
DSP	Dataspace Protocol	PIP	Policy Information Point
DSS	Decision Support System	PPP	Public-Private-Partnership
DSSC	Data Space Support Center	PRDaaS	Policy-Ready Data as a Service
DS4SSC C-DEP	Data Spaces for Smart and Sustainable Cities and Communities –Digital Europe Work Programme	PRP	Parallel Redundancy Protocol
DUET	Digital Urban European Twins	QGIS	Quantum GIS

eIDAS	electronic Identification, Authentication and Trust Services	RATP	Autonomous Parisian Transport Company *(Régie Autonome des Transports Parisiens)*
EBSI	European Blockchain Services Infrastructure	R&D	Research and Development
EC	European Commission	RDF	Resource Description Framework
EC	European Commision	REST	REpresentational State Transfer
EDC	Eclipse Dataspace Components	RESTful APIs	Follows the principles of REST
EDIC	European Digital Infrastructure Consortium	RFC	Request For Comments (technical documents published by EITF)
EIF	European Interoperability Framework	ROI	Return On Investment
EIT Digital	European Institute of Innovation & Technology	SAREF	Smart Appliances REFerence
ELT	Extract Load Transform	SDK	Software Development Kit
ETL	Extract Transform Load	SFTP	SSH File Transfer Protocol
ETSI	European Telecommunications Standardization Institute	SHACL	Shapes Constraint Language
EU	European Union	SHAP	Shapeley Additive Explanations
EU LDT Toolbox	European Union Local Digital Twins Toolbox	SIOP-2	Self-Issued OpenID Provider v2
EUDI Wallet	EU Digital Identity Wallet	SIRI	Service Interface for Real-time Information
FAIR	Findable, Accessible, Interoperable, Reusable	SKOS	Simple Knowledge Organisation System
FDSC	FIWARE Data Space Connector	SLA	Service-Level Agreement
FL (Flower-based FL)	Federated Learning – Flower (flwr) is a framework for building FL systems	SOSA	Semantic Sensor Network Ontology
GA	Grant Agreement	SNCF	National Company for the French Railways *(Société Nationale des Chemins de Fer Français)*
GDPR	General Data Protection Regulation	SPARQL	Simple Protocol And RDF Query Language
GEM taxonomy	Global Earthquake Model taxonomy	SSH	Secure Shell
GeoJSON	Geographic JavaScript Object Notation	SSI	Self-Sovereign Identities
GIS	Geographical Information System	STEP	Standard for the Exchange of Product Model Data
HTTP	Hypertext Transfer Protocol	TCUs	Terms and Conditions of Use
HTTPS	Hypertext Transfer Protocol Secure	TDT	Trusted Data Transaction

HVAC	Heating, Ventilation and Air-Conditioning	TEFs	Testing and Experimentation Facilities
ICT	Information and Communication Technologies	TLS	Transport Layer Security
IDAS	IoT Devices API and Services	TM Forum Open APIs	Suite of application programming interfaces by the TM Forum
IDFM	Île-de-France Mobilités (Paris region)	UI	User Interface
IDSA	The International Data Spaces Association	URI	Unique Resource Identifier
IETF	Internet Engineering Task Force	URL	Uniform Resource Locator
IFCs	Industry Foundation Classes	VCs	Verifiable Credentials
IFC-to-CityGML	Strict and automatic mapping of IFC - BIM models	VP	Verifiable Presentation
INSEE	French National Institute of Statistics and Economic Studies *(Institut National de la Statistique et des Etudes Economiques)*	W3C	World Wide Web Consortium
INSPIRE Directive	Infrastructure for Spatial Information in the European Community Directive	WCS	Web Coverage Service
IoT	Internet of Things	WebXR	WebXR Device API (standard for AR and VR)
IRI	Internationalised Resource Identifier	WFS	Web Feature Service
ISA	Interoperability Solutions for European Public Administrations	WGS84	World Geodetic System 1984 (globally used geodetic datum and geographic coordinate system)
ISG CIM Committee	Industrial Specification Group "Context Information Management" Committee	WMS	Web Map Service
ISO	International Organisation of Standardisation	WOL	Web Ontology Language
IT	Information Technology	WP	Work Package
ITB	Interoperability Test Bed	WPS	Web Processing Service
ITU	United Nations International Telecommunication Union	WS	Work Stream
IUDX	India Urban Data Exchange	WACML P*P architecture	Structured approach to managing and organising data within an organisation
JOSE	Java Open-Source Exchange	XML	Extensible Markup Language
JSON	JavaScript Object Notation	XSD	XML Schema Definition

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Glossary

BIM (Building Information Modeling): Method and digital process to create and manage building and infrastructure data using 3D models enriched with semantics.

🔗 buildingSMART International - What is BIM

See 3.3 A necessary link between BIM and CIM data

CIM (City Information Modeling): Extension of BIM principles to the scale of the city, integrating buildings, infrastructures, and territorial data for urban planning and smart city projects.

See 3.3 A necessary link between BIM and CIM data

CityJSON: An open format based on JSON for storing and exchanging 3D city models, aligned with the CityGML data model but simpler and developer-friendly.

🔗 CityJSON official site

See 3.3 A necessary link between BIM and CIM data

Context broker: A core component that **manages the lifecycle of context information**, including updates, queries, registrations, and subscriptions. It serves as the main interface through which context producers (e.g., sensors or devices) and context consumers (e.g., applications) interact in a decoupled, scalable manner. This core component implements the **NGSI-LD standard** to manage and exchange contextual information (entities, properties, relationships) in real time.

There are open-source broker contexts in the FIWARE ecosystem, but there are also proprietary broker contexts, notably used in North Korea.

🔗 FIWARE Context Broker

See 4.1 FIWARE

See 6.1 Why interconnect a data space and a context broker?

Data Catalog: An organised inventory of datasets and services, with metadata describing content, access rights, and formats, to improve discovery and reuse.

🔗 W3C DCAT - Data Catalog Vocabulary

See 3.5 A Data warehouse

See 3.6 The Emergence of Data Spaces: Enabling Data Transactions Across Local Authorities and Sectors

DCAT (Data Catalog Vocabulary): W3C standard RDF vocabulary for describing datasets in catalogs to improve discovery and interoperability.

🔗 W3C DCAT

DCAT-AP (DCAT Application Profile for Data Portals in Europe): European Commission profile of DCAT ensuring harmonisation across European open data portals.
🔗 DCAT-AP

Data platform: An integrated environment that combines storage, processing, cataloguing, and access services for datasets, APIs, and applications.

🔗 NIST Big Data Interoperability Framework

See **3.5 A Data warehouse**

See **Figure 7. Comparison between a data space and a data platform**

See **6.2 How do Data Spaces and Data Platforms Interconnect?**

Data space: Federated infrastructure enabling sovereign, trusted, and interoperable data sharing between organisations, under shared governance and standards.

🔗 DSSC - Key Concept Definitions

🔗 DSSC - Alphabetical List of All Defined Terms in Blueprint v2.0

See **3.6 The Emergence of Data Spaces: Enabling Data Transactions Across Local Authorities and Sectors**

See **Figure 7. Comparison between a data space and a data platform**

See **6.2 How do Data Spaces and Data Platforms Interconnect?**

Data Space connectors: Data Space Connectors are essential for enabling trust and interoperability in data sharing and exchange within data spaces. Participants in a data space need Data Space Connectors to share data because connectors enable secure and effective communication and exchange in data spaces. They are a tool to connect many data endpoints to increase the pool of available data and to accelerate the data economy. By linking Data Space Connectors, data spaces become protected environments where participants can freely share data. Data Space Connectors act as nodes in a data space and provide the required level of data sovereignty to the participants.

🔗 Data Space Connector Report

See **3.5 A Data warehouse**

See **3.6 The Emergence of Data Spaces: Enabling Data Transactions Across Local Authorities and Sectors**

See **5.3.1 Technical interoperability in practice**

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See 6.1.1 Data Space connectors

See 6.2.2 Resources to interconnection

FIWARE Data space connectors: FIWARE implementation of **data space connectors**, ensuring secure, standard-based exchange of data between participants in a data space.

🔗 FIWARE Data Space Connector

See 6.2.3 Interconnexion of Digital Twins

Data warehouse: A centralised repository that integrates data from multiple sources, optimised for analysis, reporting, and decision support.

🔗 Wikipedia - Data Warehouse

See 3.5 A Data warehouse

Digital Twin: A virtual, continuously updated representation of a physical system or territory, used for monitoring, simulation, and decision-making.

🔗 Digital Twin Consortium - Definition

See 3.2.2 Digital Twin

EDC (Eclipse Dataspace Components): Open-source set of components under Eclipse Foundation to build and operate data spaces, ensuring sovereign, secure, and interoperable data exchange.

🔗 Eclipse Dataspace Components

See 3.5 A Data warehouse

See 3.6 The Emergence of Data Spaces: Enabling Data Transactions Across Local Authorities and Sectors

See 6.1.1. Data Space connectors

GIS (Geographic Information System): System for capturing, storing, analyzing, and visualizing spatial or geographic data.

🔗 Wikipedia - Geographic Information System

See 3.4 The case of Geographic Information Systems (GIS)

Urban Data Dashboard: An urban data dashboard, on the one hand, is a digital platform that centralizes, aggregates, and visualizes real-time or near-real-time data from diverse sources (sensors, databases, specialised information systems, etc.) to provide an operational view of the territory

See 3.2.1 Data Dashboard

IFC (Industry Foundation Classes): Open standard (ISO 16739) for exchanging building and construction data, widely used in BIM.

🔗 buildingSMART - IFC

See 3.3 A necessary link between BIM and CIM data

Interoperability: The ability of systems, organisations, or applications to exchange, interpret, and use data in a meaningful and efficient way.

🔗 European Interoperability Framework (EIF)

See 2. Interoperability

Internationalized resource Identifier: A unique identifier for a resource on the web, like a URL, but supporting a wider range of characters (Unicode).

🔗 Internationalized Resource Identifiers (IRIs)

JSON-LD (**JavaScript Object Notation for Linked Data**): W3C standard extending JSON with semantic annotations, enabling linked data and interoperability.

🔗 W3C JSON-LD

Knowledge models (or **domain ontology**): In digital twins and data spaces, knowledge models provide the semantic backbone: they formalize concepts (e.g. building, sensor, flood event), relationships (e.g. isLocatedIn, measures), and constraints, ensuring that heterogeneous systems exchange and interpret data consistently. They typically take the form of ontologies, taxonomies, or reference data models (such as Smart Data Models), and are essential for achieving semantic interoperability.

🔗 EU Data Spaces Support Centre - Knowledge Representation & Semantics

See 6.3. Why contextualise Data ?

NGSI-LD (Next Generation Service Interface - Linked Data): ETSI standard API for managing context information with linked data semantics, core of FIWARE.

🔗 ETSI NGSI-LD

See 3.3 A necessary link between BIM and CIM data

See 4.1 FIWARE

ODRL (Open Digital Rights Language): W3C standard for expressing usage rights, obligations, and permissions over digital content or data.

🔗 W3C ODRL

OGC Standard Catalog Service for the Web (CSW): OGC standard interface for discovering and retrieving geospatial metadata from catalog services.

🔗 OGC CSW

Ontologies: Formal models that define concepts, entities, and their relationships within a domain, enabling shared understanding and semantic interoperability.

🔗 W3C Ontology Overview

See **6.3. Why contextualise Data?**

Executive Summary

Designed as a practical guide for Local Digital Twins for Smart and Sustainable Communities (LDT4SSC) pilot applicants, this document provides a detailed overview of the current technical landscape relevant to Local Digital Twins (LDTs), with a strong emphasis on interoperability by design. It equips stakeholders —including communities, regions, technology providers, and researchers— with the tools, standards, and best practices needed to develop seamless, scalable, and EU-compliant LDT solutions in response to upcoming open calls.

This document builds on core prior project outputs and ongoing European initiatives, such as the Data Spaces for Smart and Sustainable Cities and Communities Digital Europe Work Programme (DS4SSCC-DEP), the SIMPL framework, the European LDT Toolbox, and Minimal Interoperability Mechanisms (MIMs) Plus, to present a consolidated technical roadmap of existing tools, standards, and best practices that are not only robust, but also aligned with Europe's digital and green transitions. It highlights how pilots can achieve compliance with the LDT4SSC technical expectations and more generally the European Union (EU) policies on data sovereignty, interoperability, and sustainability, while leveraging existing tools and emerging standards to ensure cross-border and cross-sector collaboration. As such, a central focus is placed on "interoperability by design", outlining practical approaches— such as standardized data models, APIs, and governance frameworks— to enable federated, reusable, and future-proof LDT deployments. By leveraging established frameworks and "interoperability by design", pilots can achieve seamless data exchange, cross-sector collaboration, and scalable value creation. The analysis in this document further demonstrates that legal, organisational, semantic and technical interoperabilities must be embedded from the outset to ensure LDTs can connect with other LDTs, data spaces, and ecosystems without friction.

Key findings highlight that standardized data models, APIs, and governance frameworks (e.g., NGSI-LD, EDC, ODRL) are ready-to-use and should be mandatory for pilot compliance. It further states that federated architectures (e.g., SIMPL, Gaia-X) enable cross-border LDT integration, supporting EU policies on data sovereignty and digital sovereignty. Finally, another takeaway point is that AI and data valorisation must align with sustainability goals, ensuring LDTs contribute to climate neutrality and circular economy objectives.

NB: This report is directly related to the Deliverable 2.8 *Technical Landscape Report for Pilots* within the LDT4SSC project that will be made publicly available at a later stage. As an initial output of the project, the Technical Landscape Report will be further developed and complemented by additional Technical Resources gathered and produced for pilots to support pilot implementations. These resources will be shared through the project's Knowledge Hub[1] and in a separate Deliverable. Additionally, its findings will contribute to the project's interoperability Blueprint , ensuring long-term alignment with EU digital transformation policies and Green Deal objectives for a unified, innovative and sustainable European digital ecosystem.

Led by Cerema, with contributions from LIST, Libelium, Kereval, and other consortium partners, this report combines expertise about digital twin technologies, data governance, and smart city ecosystems, ensuring that the report reflects both the state-of-the-art technological advances and the practical considerations for real-world pilot deployments.

[1] See https://knowledgehub.ldt4ssc.eu/resources_content/tech_resources/#

1. Introduction

1.1 About the Local Digital Twins for Smart and Sustainable Communities

The Local Digital Twins for Smart and Sustainable Communities (LDT4SSC) project is a Digital Europe-funded (DEP) project, and as such, contributes to two main goals/directives from the European Commission (EC).These are the improvement of the digitalisation of Europe as a whole, and the improvement of citizens' lives through sustainability and projects to better preserve and protect the environment.

This project seeks to build a robust and scalable ecosystem of Local Digital Twins (LDTs) and stimulate the market for innovative, AI-driven LDT services. It builds on previous achievements such as the LDT Toolbox and the deployment project for the European data space for smart communities (DS4SSCC-DEP)[2], while integrating ongoing initiatives including the CitiVerse and the Networked Local Digital Twins towards the CitiVERSE European Digital Infrastructure Consortium (LDT CitiVERSE EDIC). Together, these efforts will establish a resilient LDT infrastructure that enables European communities to optimise urban services, share resources, and tackle shared challenges such as climate change, air quality, waste, and energy efficiency.

The project also addresses broader barriers to AI adoption in Europe, which include limited investment, regulatory complexity, and gaps in expertise. By pooling public sector demand and ensuring a fair, competitive environment for innovators, it supports the development of advanced AI-driven digital twin solutions. This approach benefits both the public and private sectors, aligns with the European Union (EU) priorities for ethical AI and open standards, and reduces reliance on foreign technologies.

In close alignment with the LDT CitiVERSE EDIC, the project accelerates the deployment of interoperable digital infrastructures across Member States, fostering cross-border collaboration. In doing so, it contributes to the Digital Europe Programme's (DEP) vision of a resilient and unified digital landscape.

To achieve this, the project pursues three objectives:

1. **Connecting existing data platforms and LDTs from cities and communities** to create a federation of LDTs across the EU. Reinforced interoperability through the aggregation of LDTs at a larger scale (cross-sectors, cross-cities, and cross-borders) will help in scaling up European common data sets and open-source solutions. It will also facilitate less advanced cities and communities joining the existing EU LDT ecosystem.
2. **Expanding existing local data platforms and LDTs with new open-source LDT services based on shared needs of cities and communities**. These services should aim to improve decision-making processes and citizen interaction, reduce risks, costs, downtime, and enhance resilience and sustainability of LDT platforms while enabling new value creation.

[2] The European data space for smart communities is an EU-wide action creating a cross-sectorial data space for governments on all levels and their providers to deliver the best possible services to their citizens by enabling interoperability to reach critical goals. See more at: https://www.ds4sscc.eu/

3. **Complementing the EU LDT Toolbox launched under WP2021-22 with additional AI-based and innovative services** (e.g. for adaptable multi-sector considerations, advanced simulation and modelling approaches including bottom-up self-organised models). The AI services will be developed and tested within existing cities/communities and be replicable in other contexts.

These objectives form the foundation of an LDT ecosystem that empowers communities to collaborate effectively while advancing Europe's digital transformation.

The LDT4SSC project is implemented by 10 partners, outlined as follows:

LDT4SSC partners				
OASC – Open & Agile Smart Cities & Communities	Luxembourg Institute of Science and Technology – LIST	European Network of Living Labs	technopolis group	Ghent University
Cerema – Climat & Territoires de demain	KEREVAL	TalTech	FIWARE Foundation	libelium

1.2 Aim of the technical landscape for pilots

The aim of the technical landscape for pilots is to inform and guide pilot applicants by presenting technical existing initiatives, tools, standards and interoperability frameworks that will support the development and deployment of interoperable, scalable and sustainable LDT services across European cities and communities.

This landscape produces early stage technical recommendations for pilot applicants responding to the projects' open calls around **three specific work strands**, each targeting a key aspect of the LDT ecosystem:

Work Strand 1 focuses on interconnecting existing LDTs across cities and communities to create a federated network that enables seamless data exchange and interoperability.

Work Strand 2 aims to develop new LDT services based on common needs, such as sustainable mobility, energy management and environmental protection, fostering scalable and replicable solutions.

Work Strand 3 is dedicated to advancing AI-driven value-added services by integrating innovative AI tools and models into LDT platforms, enhancing predictive capabilities and supporting smarter decision-making for European communities.

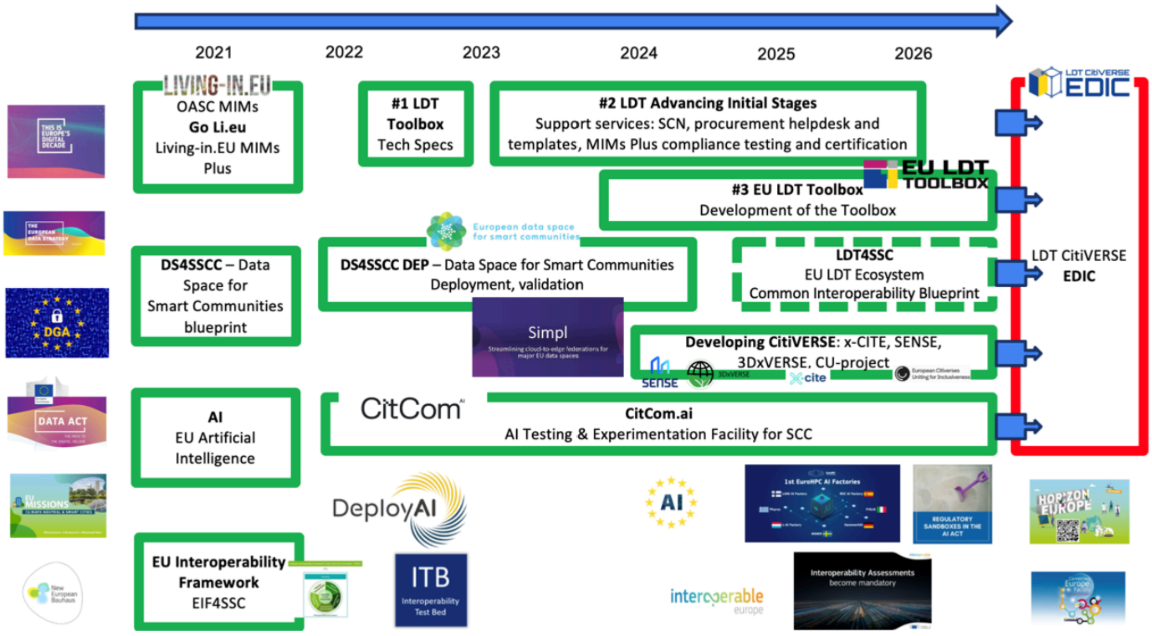

Figure 1. From DS4SSCC to LDT4SSC: LDT4SSC Smart Communities Ecosystem

The above figure sketches how LDT4SSC is positioned in the wider ecosystem of initiatives and the evolution from DS4SSCC to LDT4SSC. It presents the initiatives that the LDT4SSC project and this technical landscape report builds on and integrates, the outputs from related EU-funded projects and initiatives such as the deployment project for the DS4SSCC-DEP, the EU LDT Toolbox[3], Living-in.EU[4], CitCom.ai[5], SIMPL[6], existing knowledge tools, and stakeholder networks are leveraged. By doing so, the calls contribute directly to the DEP's objectives of enhancing technological sovereignty, promoting ethical AI and fostering an inclusive digital market while supporting policy goals like the New European Bauhaus[7], the Green Deal[8], and the Digital Decade[9].

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[3] The EU Local Digital Twin (LDT) Toolbox is a flagship initiative of the European Commission that provides a modular, standards-based suite of tools designed to help cities and communities across Europe simulate, analyse, and plan urban environments more effectively: https://interoperable-europe.ec.europa.eu/collection/ldttoolbox

[4] Living-in.EU is an EU initiative for local and regional leaders who believe that technology can help them make their town, city, or region a better place to live: https://living-in.eu/

[5] Testing AI in Smart Cities and Communities: https://citcomtef.eu/

[6] Simpl is an open source, secure middleware that supports data access and interoperability in European data initiatives: https://simpl-programme.ec.europa.eu/

[7] New European Bauhaus (NEB) is a policy and funding initiative that makes green transition in built environments and beyond enjoyable, attractive and convenient for all: https://new-european-bauhaus.europa.eu/index_en

[8] The European Green Deal is a set of policy initiatives by the European Commission with the overarching aim of making the European Union (EU) climate neutral in 2050: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[9] The Digital Decade policy programme, with concrete targets and objectives for 2030, guides Europe's digital transformation: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en

1.3 Structure of the Report

The report is structured as follows:

- **Chapter 1** describes the executive summary and introduction to the project and technical landscape report.
- **Chapter 2** presents the importance of interoperability in the LDT4SSC project, along with the context and challenges faced when it comes to implementing interoperability in digital projects. It defines the four levels of interoperability and the “by-design” approach to interoperability followed in this project.
- **Chapter 3** examines the data management challenges faced by territories and how interoperable platforms like digital twins, urban data dashboards,, and data spaces address these challenges to enable effective data valorisation.
- **Chapter 4** presents the key European initiatives enabling interoperability via a set of tools.
- **Chapter 5** covers the level of maturity of the technical tools used to assist pilot applicants in building their projects. It also provides guidance on how to put in place interoperability in practice.
- **Chapter 6** provides information on the interconnection of LDTs for pilots working on the first Work Strand.
- **Chapter 7** presents the tools, technologies and methodology used to deploy advanced use-cases in LDTs.
- **The Glossary** summarises the main technical definitions mentioned throughout the document.

2. Interoperability

This section emphasizes the critical role of interoperability with regards to effective data exchange and collaboration among diverse digital systems within smart communities. It discusses the regulatory and technological context set out by the European Union, identifies key challenges faced by public authorities, and introduces the concept of "interoperability by design" and the European Interoperability Framework as foundational principles for building future-proof time-resistent digital infrastructures.

2.1 Context and challenges

The European Union has created a strategy of trust for the development of a data economy by defining a European Data Strategy based on a set of regulations (Data Act, AI Act, Data Governance Act, Interoperable Europe Act, etc.). This European strategy promotes in particular for the pooling of data through interoperable "Common Data Spaces" (CDS) (Data Governance Act of May 30, 2022[10]). The latter defines a set of harmonised basic conditions aiming at strengthening trust (in exchanges and cybersecurity) and increasing the availability and reuse of data in accordance with the "FAIR" (Findable, Accessible, Interoperable, Reusable) principles[11].

The philosophy behind this strategy is that when there is a level-playing field in the data economy, companies compete on the quality of their services, not on the quantity of data they control[12].

At a time when the Internet of Things (IoT) is growing rapidly, as is Artificial Intelligence (AI), and data usage is becoming massive, a fundamental challenge public actors face is ensuring the sovereignty, scalability, and financial and energy sustainability of this profound digital transformation. Local authorities and governments, supported by private actors, are now building more and more data platforms, data lakes, urban data dashboards, digital twins and other solutions that collect and exploit public and private data on a massive scale.

Taking these considerations into account, the following questions arise:: How can compatibility be ensured between emerging data architectures and the legacy systems currently in use by local authorities? How can we aspire to a seamless communication / interconnection of data among different systems when some are created by separate private actors? Can consensus be achieved when competition among private actors incentivises closed, proprietary solutions?

2.2 Interoperability "by design"

The approach to data interoperability in the context of the LDT4SSC project is based on a "by-design" approach, also known as "design interoperability".

[10] See https://digital-strategy.ec.europa.eu/en/policies/data-governance-act
[11] The acronym and principles were defined in a March 2016 paper: Wilkinson, Mark D et al. "The FAIR Guiding Principles for scientific data management and stewardship." Scientific data vol. 3 160018. 15 Mar. 2016, doi:10.1038/sdata.2016.18
[12] Preamble of the Data Governance Act. See: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32022R0868#pbl_1

What is interoperability “by design”?

Interoperability “by design” refers to a system's ability to exchange and use data with other systems is built into its design from the outset, rather than added as an afterthought.

In practical terms, this means that **technical, organisational, semantical and legal choices are made from the outset** to facilitate the smooth exchange of data and services with other systems or actors. This includes, for example:

- the use of open standards for data formats,
- the implementation of well-documented APIs (application programming interfaces),
- a clear governance of access rights and responsibilities,
- and attention to the needs of partners from the design phase onwards.

Interoperability designed from the outset is also an opportunity for regions to develop seamless long-term services with the effective integration of new partners and new features at a lower cost and without necessarily having to call into question what was initially deployed, i.e. because the initial systems were not built to accommodate / evolve with change, but rather to fill one’s needs, and as such, when needs changed, what was initially deployed could have been questioned as it usually led to costly optimisations of designs, compatibility issues, data models not standardised hence not interoperable etc

The use of data, which belongs to the community, by third parties (for visualisation purposes, artificial intelligence tools for prediction etc.) will be all the more cost-effective as the data models used to understand it will be “standardised” by profession and use case.

Interoperability is therefore a catalyst for a successful digital and dynamic representation of phenomena in territories/local authorities, facilitating the exchange and sharing of data and cross-analysis to improve territorial management amongst professions, services, and territorial actors.

2.3 Four different levels of interoperability

The levels of interoperability needed for effective data circulation are well established, though described differently across documents. In this report, we explicitly adopt the **European Interoperability Framework (EIF)** as the primary reference for the defining of the levels required for effective interoperability. This framework was formalised by the EC in the context of the modernisation of digital public services to promote inter-administrative cooperation across Europe. The EIF defines interoperability through four complementary layers: **Legal**, **Organisational**, **Semantic**, and **Technical** (LOST acronym):

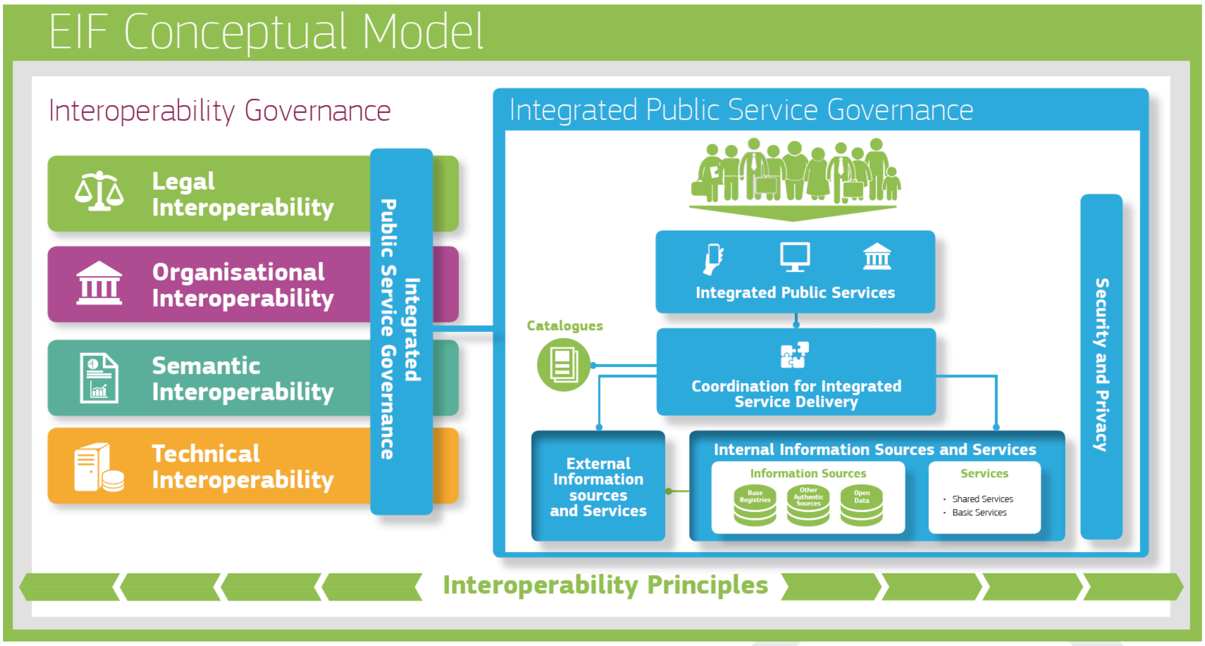

Figure 2. The EIF Conceptual model

- **Legal (L):** Ensure data sharing and use are compliant with law and agreements. It is also strongly related to having a common framework for the description of contracts and licences of usage, and to ensure legal interoperability among platforms and data spaces.
- **Organisational (O):** Align roles, processes, and commitments to deliver a joint service. It is further about providing and verifying digital identities / claims[13] from participants, organisations and users.
- **Semantic (S):** Make sure data carry the same meaning and references across all data exchanges and for all parties, so that it is automatically usable by an application after a data exchange[14].
- **Technical (T):** Connect systems using compatible standards, interfaces, and security controls.

The comprehensive model also includes a cross-cutting component of the four layers called "**integrated public service governance**", and a background layer, "**interoperability governance**".

[13] A claim is usually a statement about a particular topic (a participant, a cloud service, etc.) –for example, a claim could be about something's geolocation or the compliance with a certain regulation. Claims are digitally signed so that anyone receiving the claim can know who issued it. Self-asserted claims are created by the subject. Verifiable claims (VC) are made by others about the subject / topic –for example a local government can assert and sign a verifiable claim about a birthdate or a driving license).
[14] This means that semantically-defined data, for example, in a csv file, column titles, holds the same truth and understanding within the context (e.g. industry etc.) of its use for all parties.

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For Further Exploration: The European Interoperability Framework in detail https://interoperable-europe.ec.europa.eu/collection/iopeu-monitoring/european-interoperability-framework-detail

In the subchapter 5.3. Interoperability in practice, these four EIF interoperability layers will be translated into actionable steps, illustrating how legal, organizational, semantic, and technical interoperability can be achieved in real-world projects. It includes examples and best practices for designing interoperable data flows, agreements, and system integrations.

Example:
Illustrating the different interoperability dimensions, imagine that *person A* sells and sends *a blue car* (representing a piece of information) by train to *person B*.

Technical interoperability concerns the basic *ability to transport* the car. The train represents *the transport system* that must run from person A to person B without interruption. It relies on compatible tracks, engines, and signals; just as information systems rely on shared technical standards and communication protocols. **Syntactic interoperability, a subset of technical interoperability**, ensures that the car can be loaded and unloaded correctly. To achieve this, the car is placed in a standard container with a *unique identifier*. The container can travel by train, ship, or truck, as long as it uses a common format that both sender and receiver understand.

Semantic interoperability ensures that when person B opens the container, they can *recognise* that the contents are a blue car. In other words, the meaning of the data is *preserved* and *understood* consistently across systems. The “car” and its “blue” attribute are clearly defined and interpreted in the same way by both person A and person B.

Organisational interoperability deals with the coordination and procedures that make the exchange *functional*. The car can only be used once the payment, ownership transfer, and verification of identities have taken place. *Roles* and *responsibilities* are clear: only person B, the buyer, receives the key to the blue car, and person A, the seller, receives the agreed payment. Person B will not be able to access other cars and person A will not be able to see the payments for other cars.

Legal interoperability ensures that the entire process *complies* with laws and regulations in both person A’s and person B’s jurisdictions like customs procedures, safety standards, or vehicle registration rules. The transfer of ownership and the right to drive the car at the destination must all be legally valid.

3. Interoperability: An Essential Prerequisite for Data Valorisation in Communities

For **local authorities**, the ability to **connect information systems, share data,** and collaborate with other public or private stakeholders has become a **crucial** lever for improving service efficiency, steering public policies, and meeting regulatory requirements.

However, **interoperability is often perceived as purely technical, when in fact it is primarily strategic**. This chapter further highlights how crucial interoperability is for effective data sharing and value creation in territories/local authorities. It explains the complexity of local data systems and challenges faced by territories in data management. It then presents how LDT4SSC's meta-architecture[15] (see *Figure 4*) tries to answer these challenges by placing interoperability at its core. It further defines in detail different types of existing platforms in local/regional authorities where interoperability is a key challenge, i.e. urban data dashboards, digital twins, data spaces, in order for the reader to gain clarity about these concepts and their differences.

3.1 Data Management Challenges for Communities and How the LDT4SSC Project intends to overcome them

In the context of digital transformation, **local authorities** face an **increasingly complex** information-system **ecosystem** of new solutions, software and software components etc. Choosing the relevant solutions for them and their needs may be challenging. Their data comes from a multitude of actors and sources: internal systems, public or private partners, service providers, syndicates[16], and even national or thematic platforms (e.g. national platform of geographic information, local platform / network to manage waste etc.).

Figure 3 underlines the different sources of information and data that can feed a community, all-the-more when considering local/regional authority means to implement a data space. This raises a fundamental question: **How can interoperability and data sharing among these systems be ensured to support effective public policymaking?**

The complexity of information systems stems from the **gradual layering of solutions**, often tailored to specific professions or one-off needs. Each department (finance, human resources, urban planning, waste management, etc.) typically has its own dedicated information system. In municipalities or public inter-municipal cooperation establishments, different software programmes are generally used for managing water, sports facilities, family services, technical services, and more. These tools, designed to meet precise operational needs, have gradually replaced paper files and then Excel spreadsheets, but **were not always intended to interact with each other**.

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[15] I.e. a high-level/overarching architecture of multiple underlying architectures within the ecosystem of European LDTs that helps guide and coordinate these smaller technical architectures, while consolidating existing initiatives to foster interoperable platforms.
[16] A syndicat de communes, or syndicat intercommunal, is a category of public establishment for intercommunal cooperation without its own tax status.

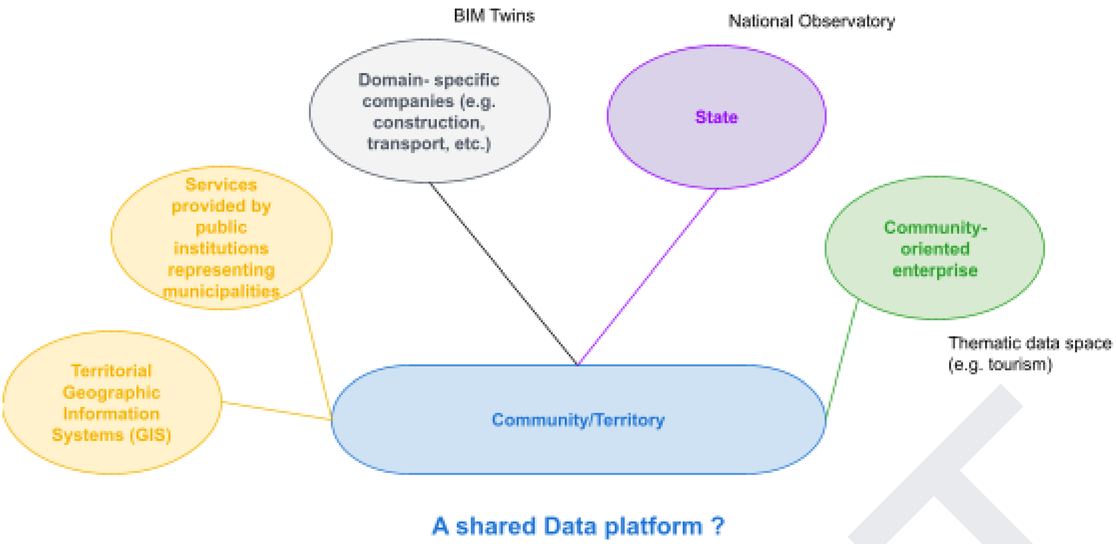

Figure 3. Overview of the different organisations feeding data into a territory/local authority –a data ecosystem for territories

To better leverage their data, **some local authorities have implemented decision support systems** (DSS) or visualisation tools like Power BI, Superset, or Digdash. Additionally, Geographic Information Systems (GIS) often play a key role by structuring territorial data into cartographic layers.

The **2007 INSPIRE (Infrastructure for Spatial Information in the European Community) Directive**[17], which aimed to **establish a geographic information infrastructure to promote environmental protection**, **required public authorities to make these data accessible to the public** by publishing them online and to share them amongst themselves. Beyond creating obligations, it facilitated implementation through the publication of technical texts: **European regulations and best practice guides**[18], leading to the establishment of data models in most fields. **Open data platforms** have also **emerged**, making certain public data accessible to the public. These are platforms that simply allow the deposit, cataloguing, and retrieval of data that is accessible under an open-data licence.However, these data processing and openness **initiatives** often **remain disjointed**. They are insufficient to create a unified information system or meet the cross-cutting needs of decision-makers.In particular, the databases of professional software remain largely closed, and **shared data** between departments and actors is **still uncommon**.

What is Shared Data?

Shared data refers to **data made available to other stakeholders within a defined framework**, often bilateral or contractual. Unlike **open data**, which is **freely accessible to**

17 https://eur-lex.europa.eu/EN/legal-content/summary/the-eu-s-infrastructure-for-spatial-information-inspire.html
18 https://knowledge-base.inspire.ec.europa.eu/evolution/good-practice-library_en

all with minimal usage restrictions, **shared data** is exchanged with a limited number of actors, according to **specific rules** (usage rights, purposes, duration, confidentiality, etc.).

This type of data can be strategic, sensitive, or simply not intended for public release, yet it may hold significant value for specific partners (local authorities, businesses, researchers, etc.). Sharing such data **fosters collaboration, creates value, or supports shared services**, all-the-while **maintaining control** over its use.

Example: A local authority shares real-time traffic data with a mobility operator as part of a partnership to improve transportation services. While this data is not published as open data, its targeted sharing enhances system interoperability and service efficiency.

Although some local authorities have implemented **ETL (Extract, Transform, Load) tools** to ingest and transform data - and have included application programming interface (API) requirements in their specifications for acquiring dashboards (supervision) - the circulation, linking, and reuse of data remain complex among the various deployed technical solutions.

The overall vision of LDT4SSC is to consolidate the existing architectures and best-practices defined in prior work for LDTs into a clear and actionable evolving interoperability blueprint. This blueprint will be updated to reflect on the learnings of the pilots and can serve as a tool to facilitate and speed up the go-to-market processes of future digital twin developments, particularly for local authorities. It draws heavily on prior work done by the Data Space Support Center (DSSC)[19], DS4SSCC-DEP[20], the Living-in.eu MIMs Plus[21] and others.From this prior work, we recognise that an overarching meta-architecture is emerging for European LDTs, that will allow a fair and level-playing field for technology providers and procurers alike. This meta-architecture has interoperability at its core, and will stimulate a strong and dynamic innovative market fueled by the public sector. Considering the complexity of LDTs, this may well have repercussions in other sectors in demand of complex, systemic and AI-powered simulation and prediction capabilities.

LDT4SSC answers these challenges with the components presented in Figure 4.

The overarching meta-architecture can be summarised as follows:

1. Data systems and Platforms that are set up within local ecosystems are augmented with Trust Frameworks, Publication and Discovery Services, as well as Access and Usage Policies to create a Data Space (DSSC Data Space Blueprint v1.5[22]).
2. Data Spaces become interconnected, through, among other mechanisms, Data Space Connectors (see the International Data Spaces Association (IDSA) Data Connector report[23]).

[19] https://dssc.eu/
[20] https://www.ds4sscc.eu/
[21] https://mims.oascities.org/NzWXOO1Fttw4wtqv1Wys/
[22] See: https://dssc.eu/space/bv15e/766061169/Data+Spaces+Blueprint+v1.5+-+Home. The version 2.0 is now out: https://dssc.eu/space/BVE2/1071251457/Data+Spaces+Blueprint+v2.0+-+Home
[23] A comprehensive overview of available data space connectors based on the IDS Reference Architecture Model: https://internationaldataspaces.org/wp-content/uploads/dlm_uploads/IDSA-Data-Space-Connector-Report-1_October_2025-1.pdf

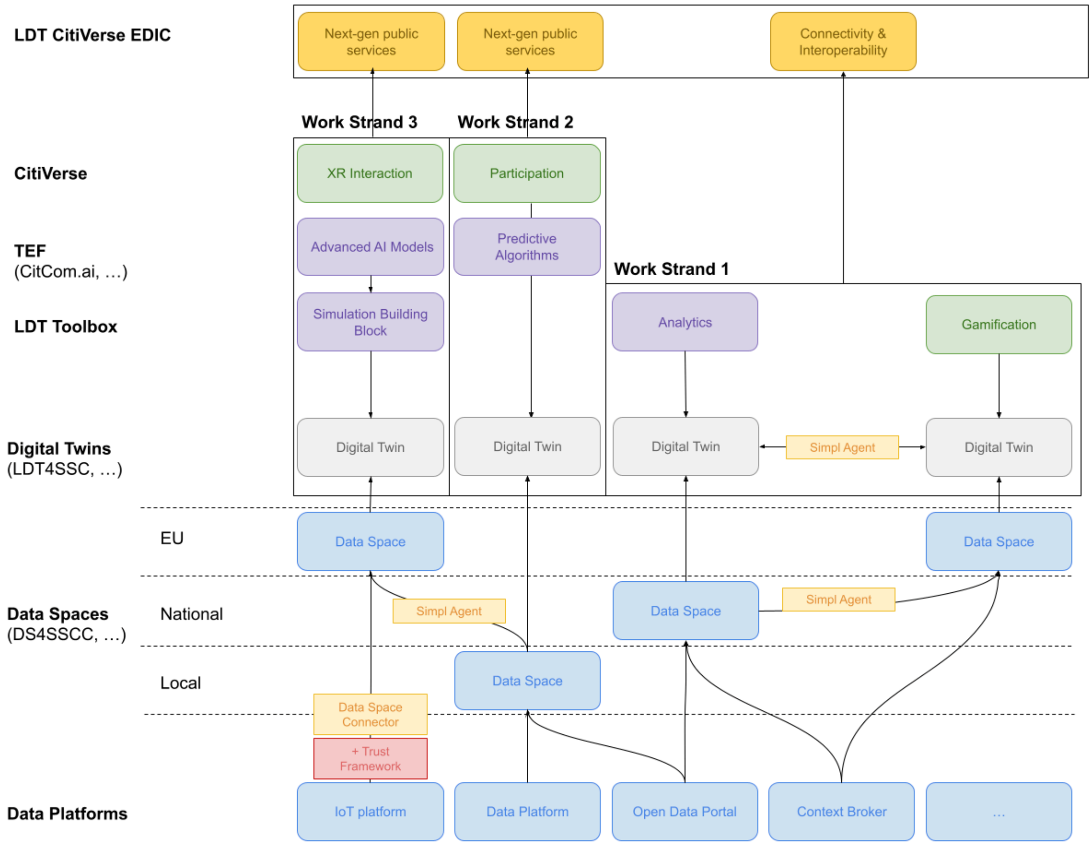

Figure 4. Meta-architecture for LDTs and Value-added services

3. These local or regional Data Spaces are federated in European Data Spaces, through the SIMPL (Smart Middleware) Programme[24], funded through the EU project DIGITAL Europe.
4. On top of these Data Spaces, Local LDTs are developed, using components from the EU LDT Toolbox, and other components available through various suppliers.
5. Within the Testing and Experimentation Facilities (TEFs)[25], advanced AI and machine learning tools and models are made available to further increase the effectiveness of the services developed within the LDTs.
6. Interoperability is built into these value added services, thanks to the Minimal Interoperability Mechanisms (MIMs) Plus[26] framework and the EIF[27]. This way, these can benefit other communities. These are therefore fed back to the LDT Toolbox Marketplace (repository) and disseminated.
7. Sustainable operation of these value-added services and the underlying connectivity, infrastructure and interoperability is guaranteed by the European Digital Infrastructure Consortium (EDIC), and in this case specifically, the LDT CitiVerse EDIC.

[24] See footnote 5: https://digital-strategy.ec.europa.eu/en/policies/simpl
[25] See https://digital-strategy.ec.europa.eu/en/policies/testing-and-experimentation-facilities
[26] The minimal interoperability mechanisms (MIMs) Plus enable a minimal but sufficient level of interoperability for data, systems, and services specifically in the context of smart city solutions: https://living-in.eu/group/7/commitments/mims-plus-version-8-2025
[27] See footnote 15: https://interoperable-europe.ec.europa.eu/collection/iopeu-monitoring/european-interoperability-framework-detail

At the bottom of the diagram are the types of platforms deployed in the territories/local authorities. At the same time, thematic data spaces are being deployed (EONA-X[28] at European level, for example, and Agdatahub[29] in France).

The aim is for all platforms to be able to interconnect and manage all contractual aspects related to data, which is not the case today.

The creation of LDTs is a more advanced version of data management, as it allows for the incorporation of simulations, and their interconnection requires the management of all contractual rights related to data. This interconnection can be done, ideally, by connecting to another LDT via a data space (see Glossary) or via a federated broker. A data space can be managed either in a structured way (using Data Space Connectors, SIMPL agents), or in a specifically managed way (data space infrastructures providing file transfers, API push –or pull– services).

3.2 Types of existing platforms in communities where interoperability is a key challenge

Faced with the proliferation of specialised supervisory tools and the need to break down data silos, several solutions are emerging to support decision-making, stakeholder coordination, and understanding of local dynamics. Two closely-related but distinct concepts – **urban data dashboards and Local Digital Twins**– address these complementary objectives.

3.2.1 Data Dashboard

An **urban urban data dashboard,** on the one hand, is a **digital platform that centralizes, aggregates, and visualizes real-time or near-real-time data from diverse sources** (sensors, databases, specialised information systems, etc.) to provide an **operational view of the territory**. It enables decision-makers and operators to **monitor the territory's/local authority's status** (traffic, energy consumption, air quality, safety, etc.), detect anomalies, manage urban services, or handle crisis situations. Functioning as an **advanced dashboard**, the urban data dashboard (sometimes also called a hypervisor) is characterised by its ability to deliver real-time indicators, cross-reference data, and facilitate immediate action. It is particularly suited for operational use by local authority services, operators, and technical partners.

3.2.2 Local Digital Twin

An **LDT**, on the other hand, is a **virtual replica of a territory based on structured data models, real-time data feeds, and potentially 3D representations**, which can **integrate simulation models** (flows, usage, impacts, etc.). It aims to **dynamically represent the territory at various spatial and temporal scales to analyze, understand, anticipate, and simulate** the effects of public policies, environmental hazards, climate change, development projects or disruptions. The digital twin **supports strategic decision-making**, consultation,

[28] EONA-X is a non-profit association that aims to "[redefine] data sharing to enhance efficiency and foster innovation". https://eona-x.eu/

[29] "Agdatahub federates public and private players to support and facilitate the digital transformation of the agricultural world based on use cases meeting real needs and strong challenges". https://agdatahub.eu/en/entreprise/

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foresight, and scenario design. It can even include automated decision making and execution (actuation). It can incorporate historical datasets, time-delayed data, real-time data, **Building Information Modeling** (BIM), Geographic Information Systems (GIS), and / or specific models (mobility, climate, energy, etc.).

A. Local Digital Twin's Lifecycle

The lifecycle of Local Digital Twins generally includes **three phases**[30][31]:

- **Design:** At this stage, only the digital component of the twin exists, primarily consisting of static models coupled with simulators, often featuring 3-Dimensional (3D) visualisations.
- **Operation:** Here, both the physical and the digital twins coexist. The digital twin is synchronised with the real twin (which can be tangible, like a building, or conceptual, like a weather forecast) at a frequency and fidelity specific to the use case. Information generated during the design phase (geometric data) facilitates visualisation.
- **Decommissioning:** At this stage, data can be recycled to feed a new design cycle or reused (e.g. in component repurposing etc.). This aspect is currently a subject of research and development (R&D), linked to the circular economy.

During the operational phase, the use of contextualised information describing entities in their environment –including their properties, functions, states, and relationships— enables the digital twin to be "animated."

Other standardisation initiatives exist as well, such as *the Guidance for the Integration of Digital Twins in Data Spaces*[32] by the WG Standardisation Focus Group High Level Architecture, BDVA Task force Data space, Task force Standards and benchmarking, and TWG – Digital Twins, which highlights a lifecycle view of digital twins according to a process based in different steps: 1) The inception of LDTs; 2) Their design; 3) Their deployment; 4) Their operating and monitoring processes; 5) Their retirement, when relevant; and 6) Their verification and development.

B. Local Digital Twins' functions

The Guidance for the Integration of Digital Twins in Data Space further details a list of potential Digital Twins' functions, as presented in Table 1 below (in two parts).

[30] See section 6.3: https://www.etsi.org/deliver/etsi_gr/CIM/001_099/017/01.01.01_60/gr_CIM017v010101p.pdf
[31] These lifecycle steps must not be confused with the the 4 steps of the LDT4SSC Methodology: Explore, Validate, Define and Implement, that provide awarded pilots an operational framework to implement their LDTs.
[32] For more information, see: https://aioti.eu/wp-content/uploads/Guidance-for-the-Integration-of-Digital-Twins-in-Data-Spaces-Final.pdf

	Define	Execute	Monitor and measure	Analyse	Control	Optimize
Inception	Profiling business processes Definition of goals and needs	Profiling business processes Definition of goals and needs	NA	Profiling business processes Definition of goals and needs	Profiling business processes Definition of goals and needs	Geometry modelling Kinematics
Design	Model design Digital thread design Digital twin system design	Better understanding and selection of tools, techniques and data	Visual design Simulation of digital twin implementation process	Better understanding and analysis of physical entities	Reduce system cost	Realize design optimization
Deployment	Modelling and simulation	Better use of tools, technology, and data	Upgrade visualization	Better analysis of generated data and simulation results Better evaluation of existing physical entities	Better integration of control equipment, systems, environments, etc. Reduce system costs	Improve implementation efficiency
Operation and monitoring	Full interaction with physical entities	Construct platform Achieve interoperability Achieve client availability	Real-time and visual monitoring Real-time and visual metering	Cost estimation Failure analysis Improved material management Operational trade-off analysis	Alarming Repairing Calibrating Inventory management Troubleshooting Planning	Reduce operating costs Prediction prognosis Sustainability Enhance user experience Reduce carbon emission
Development and verification	Model training Improve simulation	Better use of artificial intelligence, Large-scale models, machine learning, deep learning, and other technologies; Upgrade and update digital twin system	Visual monitoring Safety check Health check Counterfeit detection	Upgrade analysis	Upgrade analysis	Reduce operating costs Prediction prognosis Sustainability; Enhance user experience; Reduce carbon emission
Retirement	Replacement by other digital twins	Construct historical database	Education and training Visualization practice and rehearsal	Scientific research Provide technical support	Archiving	Utilization for other applications

Table 1. List of potential Digital Twins' functions

As such, Table 1 further develops the previously-mentioned lifecycle view of Digital Twins according to a process based on different steps.

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NB: Rows are the lifecycle processes of the digital entity and/or the target entity (note that these might be different –i.e. as in a pre-existing natural environment)[33].

Example
To create a dynamic carbon emissions' assessment of a territory/local authority, it would be necessary to gather multiple pieces of information from various specialised applications, cross-reference them, and derive actionable insights to support decision-making processes for future projects (promoting soft mobility, speed limits, waste recycling, renaturation, etc.) and their impact on the area's decarbonisation trajectory.

C. Local Digital Twin's Capabilities

Capabilities of a Local Digital Twin are largely described in MIM8 Local Digital Twins. However, more basic capabilities, generally relating to the "data journey" and applicable to more domains than Local Digital Twins alone, are covered in the "foundational MIMs", e.g. the NGSI-LD standard (MIM1 Interlinking Data) enables **several capabilities for digital twins:**

- **Descriptive:** Current (and past) state of the real world asset –static and dynamic. Bidirectional connection between real-world assets and the Local Digital Twin.
- **Predictive:** Extends the descriptive twin capability by providing predictions on the way the real asset could evolve in the future, using predictive models to envision possible futures.
- **Prospective:** Conducts "what-if" analyses to evaluate the potential consequences of actions.
- **Prescriptive:** Extends (or, in extreme cases, executes) the prospective capability with suggested actions on the real system to achieve a given objective based on the analysis.
- **Diagnostic:** Explains situations or alerts about deviations from expected conditions. Capability for evaluating what happened, especially in case of malfunction of the real asset.

	Convergence	Capability	Integration	Time
Level 1	Disconnected	Descriptive - Mirroring	Task specific	Unlinked
Level 2	Synchronized	Diagnostic – Monitoring	Connected	Linked
Level 3	Federated	Predictive - Modelling and simulation	System views	Dilated
Level 4	Collaborative	Optimized - Prescriptive	SoS - Value chain augmented view	Synchronized
Level 5	Unified	Autonomous	Enterprise - Supply chain supervising views	Integrated

Table 2. Digital twin potential maturity model

Conversely, the Guidance for the Integration of Digital Twins in Data Spaces defines five other –very similar– potential maturity levels in Digital Twins (see definition above and Table 2 for more).

33 See: https://aioti.eu/wp-content/uploads/Guidance-for-the-Integration-of-Digital-Twins-in-Data-Spaces-Final.pdf

More and evolving information on Local Digital Twin features and capabilities can be found in the documentation of the MIM Plus 8[34].

D. Local Digital Twin Interoperability

The Guidance for the Integration of Digital Twins in Data Spaces also defines several types of interoperability specifically in the context of LDTs to be distinguished among: 1) Inner interoperability; 2) Outer interoperability; 3) Transversal interoperability between Digital Twins. Figures and further information on this are given in the document.

Again, more and evolving information on Local Digital Twin interoperability considerations can be found in the documentation of the MIM Plus 8 Working Group.

E. Local Digital Twin's Standardisation

When it comes to LDTs, NGSI-LD is a very important standard that is being used in many of the initiatives part of the LDT4SSC Community. **The European Telecommunications Standardization Institute (ETSI) NGSI-LD[35] specification** defines a **pivot model and an API** for publishing, querying, and subscribing to data **represented by knowledge models**. It aims to facilitate the open exchange and sharing of structured (contextualised) information among different stakeholders in application areas such as smart cities, the industry of the future, digital agriculture, and more generally for the Internet of Things (IoT), cyber-physical systems, and digital twins.

The NGSI-LD information model represents contextual information as entities that have properties and relationships with other entities. This model is derived from attributed graphs (property graphs), with formal semantics defined on the basis of Resource Description Framework (RDF) and the semantic web framework. It can be serialised in JSON-LD format. Each entity and relationship must be assigned a specific reference, or Unique Resource Identifier (URI), which is, as stated, an identifier that makes the corresponding data exportable to the "Web of Data." The suffix "-LD" specifically refers to this affiliation with the world of Linked Data.

Another standardization initiative is underway on the topic of LDTs, building on recent efforts in IoT, Digital Twins, and data spaces. According to The Guidance for the Integration of Digital Twins in Data Spaces, the standardization roadmap in ISO/IEC has already begun incorporating the digital twin domain: ISO/IEC JTC 1/SC 41, originally focused on IoT, was expanded in 2020 to include digital twins, leading to the publication of ISO/IEC 30172 (digital twin use cases) and ISO/IEC 30173 (concepts and terminology), with ISO/IEC 30188 (digital twin reference architecture) currently in development and targeted for release around 2025.

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[34] https://mims.oascities.org/NzWXOO1Fttw4wtqv1Wys/mim8-local-digital-twins

[35] The acronym **NGSI** stands for **"Next Generation Service Interfaces"** and originates from a set of specifications initially developed by the **OMA (Open Mobile Alliance)**, which included context interfaces. These were later adopted as **NGSIv1** and **NGSIv2** by the **European Future Internet Public-Private-Partnership (PPP)**, leading to the creation of the **open-source FIWARE community**.The integration of **Semantic Web technologies (Linked Data)** culminated in the **NGSI-LD specification**, developed by the **European Telecommunications Standards Institute (ETSI)** within the **Industrial Specification Group "Context Information Management" (ISG CIM)**. This specification represents the culmination of decades of research in **context management and modeling**.

These standards provide a foundational, conceptual and architectural framework, which can be specialised for LDTs. Moreover, new standardization work is also kicking off in the data space domain: ISO/IEC JTC 1/SC 38 is developing ISO/IEC 20151 for data space concepts and characteristics, while SC 41 has preliminary work items on integrating IoT and digital twins, including “data extraction” and twin-to-data-space interoperability.

Furthermore, it is important to note that there is a joint working group between the IEC Smart Systems Committee and JTC1 that is working on a gap analysis report for standards for City Information Modelling and Urban Digital Twin. Standardisation efforts are ongoing in the ITU SG20 on Digital Twins and IoT and Smart Cities as well.

3.3 A necessary link between BIM and CIM data

Building Information Modeling (BIM) focuses on **modeling individual buildings and infrastructures**, providing a detailed digital representation of structural elements like walls, windows, and mechanical systems. It enables **precise project management,** stakeholder coordination, and optimisation of design, construction, and building operation processes. A BIM’s 3D volumetric modeling is highly detailed, incorporating specific information about materials, energy performance, and component lifecycle data.

Building upon BIM, City Information Modeling (CIM), operates at the **scale of an entire city or territory/local authority, integrating urban infrastructure, transportation systems, green spaces, and public services**. Unlike BIMs, which concentrate on specific structures, CIMs adopt a broader, more holistic approach to urban systems. They provide an overview of the relationships amongst buildings, transportation networks, energy infrastructures, and public services. CIM models 3D solids only by their boundaries, and may be less detailed for individual objects, prioritizing the representation of spatial and functional relationships among urban entities.

Transforming BIM data into CIM data involves **converting and aggregating levels of detail and context**. Highly detailed BIM data for buildings and infrastructure is often **simplified** to fit the broader urban scale, where fine details are less critical, but **spatial relationships and overall functions become more important**.

For example, specific material properties, or heating, ventilation and air-conditioning (HVAC) systems detailed in BIM models may be aggregated into simpler geometric representations in a CIM model, while retaining critical information about location or energy performance at the urban scale.

In terms of **data formats**, **Industry Foundation Classes (IFC)** are an **open, standardised file format used in BIM to exchange and share information** among different software and construction industry stakeholders. Developed by **buildingSMART International**, IFC ensures **interoperability amongst BIM applications**, enabling architects, engineers, contractors and other stakeholders to effectively collaborate throughout a construction project’s lifecycle from design to operation.

IFC files model construction objects such as walls, windows, doors, and mechanical systems, along with their associated data (geometry, material properties, technical information, etc.), thus **facilitating collaborative and multi-tool construction data management**. This standard is **software-independent**, making it essential for communication amongst different BIM systems and stakeholders, regardless of the platforms they use.

For **CIM**, **CityJSON** is a JSON-based data format designed to represent 3D urban models following the CityGML standard, commonly used for city modeling. CityJSON simplifies the storage and exchange of complex geospatial information, making it more readable and lightweight compared to traditional Extensible Markup Language (XML) formats. It efficiently structures urban objects (buildings, roads, infrastructure, etc.) while supporting 3D geometries and semantic information associated with these objects.

IFC data can be converted to CityJSON using tools like IFC-to-CityGML or specialised converters such as BIM2CityGML, preserving essential geometric and semantic information about buildings and infrastructure while adapting the level of detail to meet 3D urban modeling requirements.

Based on the **JSON-LD standard**, the **NGSI-LD** standard from FIWARE supports all GeoJSON geometry types: Point, LineString, Polygon, MultiPoint, MultiLineString, MultiPolygon, and GeometryCollection in the geometric information model. Thus, contextual information provided with the GeoJSON geometry property can be interpreted by most popular GIS nowadays.

The **ISG Context Information Management (CIM) committee** is currently studying the use of **NGSI-LD** to interconnect with **BIM systems**. Several options are under consideration:

- **Option A – BIM as a Link:** Data linking. In this scenario, **BIM data** (using the **IFC data model**) and **NGSI-LD data** remain in their separate systems or "silos." Core NGSI-LD entities can be linked to external data models, which do not need to be fully NGSI-LD compliant.

- **Option B – Mapping Key BIM Concepts via an NGSI-LD Domain Model:** BIM data collected from the BIM system is converted into the **NGSI-LD data model**, using existing cross-domain NGSI-LD ontologies. This involves mapping each class to a corresponding NGSI-LD entity and converting the data accordingly.

- **Option C – BIM Smart Model:** Creation of an **NGSI-LD domain model** equivalent to IFC concepts. This approach involves developing a domain-specific NGSI-LD model by identifying similar or equivalent concepts in both systems and creating a mapping among them. This allows for data to be translated or transformed from one system to another, enabling interoperability.

Integrating **BIM with NGSI-LD models and APIs** presents a promising approach to enhance data sharing, collaboration, and innovation in building construction and management. By adopting a **multi-scale approach** that considers semantic, geospatial, and temporal aspects, stakeholders can achieve seamless data exchange and improved decision-making throughout the building lifecycle. The report provides a comprehensive framework and practical solutions for implementing this integration.

Relevant Reports:

- Aligning with Geo-Information: https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=69099
- Using NGSI-LD in the Context of Building Information Modeling (BIM): https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=69100

3.4 The case of Geographic Information Systems (GIS)

Geographic Information Systems (GIS) are **data platforms that centralise all geographic information**. There are several GIS providers, including open-source solutions like **PostGIS** and standalone software **QGIS**, but **ArcGIS®**, a proprietary solution, is widely used.

The development of GIS was strongly supported by governments. These platforms **consolidate all geographic information for cities in one place**, representing a significant advancement in urban management. Additionally, the **INSPIRE Directive** played a key role in advancing the geographic data ecosystem by promoting the use of shared data references.

However, the use of GIS tools has certain **limitations**, particularly in terms of **openness and interfacing with other systems**.. First, the **Open Geospatial Consortium (OGC)** has undertaken efforts to modernize its interfaces (WMS, WFS, WCS, WPS, etc.) by defining **OGC APIs**, which are resource-centric and based on current web interface technologies. However, these interfaces remain focused on geospatial information.

In the minimum interoperability mechanisms, the geospatial aspect is addressed at the **MIM7 (Geospatial Data)** level, but its relationship with **MIM0 (Accessing Data) and MIM1 (Interlinking Data)** is currently poorly defined. To advance on this topic, **ETSI ISG CIM** is producing a report on the use of geo-information with **NGSI-LD**. The report covers cases such as real estate management, urban infrastructure, mobility, and disaster management, which require the integration of geospatial information with other types of data.

Technical challenges identified during interviews with several European cities include[36]:

- **Coordinate Reference Systems (CRS) management** in platforms: There is **no single reference system that satisfies all geolocation** and use cases.
- A major challenge is that some **datasets** use geographic coordinates to locate objects, while others cover buildings, addresses, or objects like streetlights. Some data may require identifiers for rooms within buildings. Other datasets may relate to areas and surfaces.
- There is also a need for **semantic interoperability**, as different datasets may have varying interpretations of what constitutes a room within a building. For example, in some countries, the ground floor of a building is called the "1st floor," while in others, the "1st floor" refers to the floor above the ground floor.

[36] Carried out in the CAPACities Program. See more: https://smart-city.cerema.fr/programme-capacities

For Further Exploration: Usage of geo-information with NGSI-LD https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=69098

3.5 A Data warehouse

A **data warehouse** is a **central, decision-support** platform that consolidates heterogeneous data from the authority's systems (finance, HR, schools, mobility, energy, etc.) into a **common model** (typically star/snowflake), with **history**, **quality controls** and **lineage** to deliver trustworthy Key Performance Indicators (KPIs), dashboards, and cross-cutting analytics. It is fed by Extract-Transform-Load or Extract-Load-Transform (**ETL/ELT**) pipelines (mostly batch, sometimes near real-time) under strong **governance** (data catalog, reference data, access management, GDPR compliance). Key takeaways:

- versus a **data lake**, the warehouse stores **clean, modelled data** (*schema-on-write*) while the lake keeps raw data (*schema-on-read*);
- versus a **data space** (see next section **3.6 The Emergence of Data Spaces: Enabling Data Transactions Across Local Authorities and Sectors**), it focuses on the **authority's central scope** rather than a federated multi-organisation ecosystem.

As data management solutions evolve, **the concept of data lakehouse is emerging.** It is a data platform that combines the flexible data storage of data lakes with the high-performance analytics capabilities of data warehouses, by pairing the capacities of both to form a better data-management system[37].

3.6 The Emergence of Data Spaces: Enabling Data Transactions Across Local Authorities and Sectors

A **data space** (or *dataspace*) is an "Interoperable framework, based on common governance principles, standards, practices and enabling services, that enables trusted data transactions between participants"[38] defined by the DSSC. This system allows participants to **retain control over their data**, including storage location, while developing use cases within a specific sector or public policy context.

Unlike centralised platforms, data spaces do not require a single storage location for data. Each participant maintains ownership of their data, which is shared according to freely-established governance rules. This approach promotes flexible interoperability while respecting digital sovereignty.

Figure 5 illustrates the interactions between the different participants in a data space. These participants require access to data they do not own in order to complete their respective missions. The data space addresses this need by enabling structured data sharing and exchange within a specific thematic area or across multiple thematics. In this way, data spaces provide a practical response to the complexity of data-sharing requirements.

In Figure 5, 'Governance' represents a local authority whereas the 'Organisations' are the data providers that will share their data with local authorities through the data space. An

[37] See more: https://www.ibm.com/think/topics/data-lakehouse

[38] See https://dssc.eu/space/bv15e/766061351/Introduction+-+Key+Concepts+of+Data+Spaces

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organisation that consumes data (may it be open or not) from a local authority may as well produce a service that is consumed by other organisations within the same data space, hence the interconnected arrows within the different actors in Figure 5. As such, a data space offers a lot of exchange capabilities to its participants.

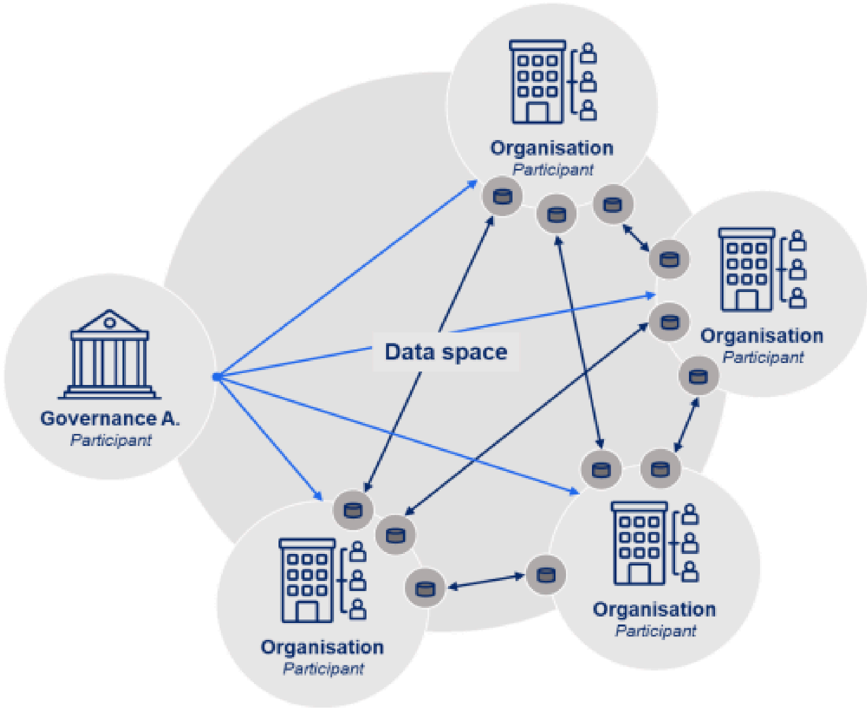

Figure 5. Basic structure of a Data Space (source: SIMPL)[39]

In France, the **Caisse des Dépôts** (French National public bank) highlights five key benefits of data spaces[40]:

1. Strengthening the **economic and environmental competitiveness** of a sector.
2. Securing the supply of **qualified data** essential for Data/AI innovations.
3. Contributing to the **efficiency of public policies**.
4. Accelerating the implementation of the **ecological transition** at the national level.
5. Ensuring **digital sovereignty** and technological independence for French sectors.

A data space relies on several key services:

- **Governance services:** Managed services that ensure the defining of common rules, enforcing of compliance with regulations, providing and verifying the identities and claims of participants (organizations, people, applications, connectors….), defining of the semantic standards applicable to data products.

- **Data Transaction services**: Managed services that allow to conclude Trusted Data Transactions between participants. It includes:

[39] See https://data-sharing-festival.net/wp-content/uploads/2024/12/Nicolas-Auricchio-Simpl.pdf
[40] Caisse des Dépôts | Décodons les espaces de données I Février 2025 : https://cdn.fs.agorize.com/nU8QeTWLRyOOZ4V1WAU0

- **Data Catalog**: A directory of available data products, facilitating discovery and accessibility.
- **Data product publication services**: to make visible in the catalog the data products available, with all the descriptive metadata necessary to conclude a transaction (type of data, type of delivery, distribution conditions, price, etc.).
- **Data product discovery services**, to facilitate the identification of the right data products for the data acquirer.
- **Trusted Data Transaction services**: conclusion of a data transaction between data provider and data acquirer, with all the contractual and usage conditions attached, as per the future Trusted Data Transaction EU harmonised standard.

- **Data Transfer services:** tools enabling technical interoperability between participants, to transfer or provide access to the data once a Data Transaction has been agreed. These services can be of two types:
  - **Decentralised Data Space Connectors:** connectors such as Eclipse Dataspace Components (EDC)[41] connector, SIMPL Agents[42] or Data Transfer Agents[43], that allow decentralised peer-to-peer transfer / access to the data. Decentralised data space connectors are useful when the data product contains data which is very sensitive or confidential, or when data transfer requires maximum security measures.
  - **Managed Data Transfer services:** technical means such as file upload, API push or API pull, which are managed by a centralised infrastructure. These services are relevant when confidentiality or security are not paramount, and when participants prefer to use managed services rather than to face the cost and complexity of deploying decentralised connectors in their local infrastructure.
- **Value creation services:** use case applications, tools and applications that create business value on the basis of data that has been acquired through the data space. This includes Digital Twins, Digital Product Passports, AI agents, Data visualisation tools, etc.

Finally, **security, trust and sovereignty are crucial concerns in data spaces** for data transaction, data transfer (decentralised or managed), participants onboarding, etc., but there is **no security infrastructure per se**. Security must be ensured in all stacks of the data space infrastructure, and in all processes.

Figure 6 presents the functional architecture of a data space as defined in SIMPL. It shows that a data space has several key characteristics. First, it is sector-specific: it is neither a

[41] EDC is a framework that implements the Eclipse Dataspace Protocol.
[42] See the Simpl architecture specification: https://code.europa.eu/simpl/simpl-open/architecture/-/blob/master/functional_and_technical_architecture_specifications/Functional-and-Technical-Architecture-Specifications.md?ref_type=heads
[43] See: https://gitlab.com/gaia-x/gaia-x-community/data-transfer-agent/-/tree/poc-walt-id?ref_type=heads

software publisher nor a data platform. Whatsmore, it brings together a diverse group of stakeholders. These may be private and/or public stakeholders, data owners and/or users, as well as technology stakeholders who produce technological building blocks.

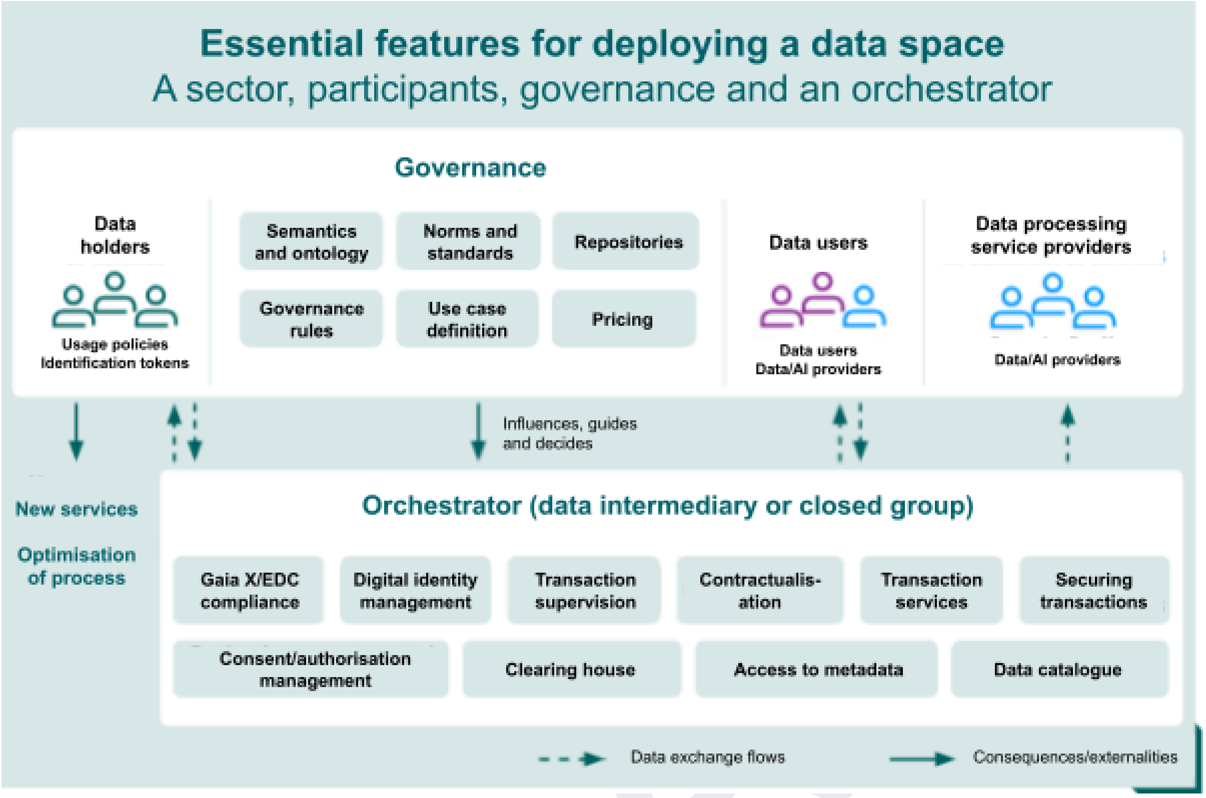

Figure 6. Functional architecture of a data space (source: Caisse des dépôts)

The data space is based on a two-tiered organisational structure. The first level is the strategic governance, which is responsible for managing relations among participants. This governance includes: defining an organisational, legal and economic framework; reusing, adapting or designing domain ontologies and semantic interoperability standards; and finally, defining use cases and pricing agreements. The second level is the technical orchestration, which includes: identifying the orchestrator; defining their roles; implementing industry governance rules; and managing the technological infrastructure that secures data transactions.

NB: In Figure 6, the governance tier is in reality also in the perimeter of the orchestrator, as it is the governing body that enforces compliance, common rules, semantics, etc.

This data space allows participants to deploy their use cases among themselves, either in a closed group or more broadly within a sectoral industry, via a Data Intermediation Service Provider (DISP)[44].

Finally, the data space prioritises use cases within sectors, with the aim of resolving business issues and simplifying processes.

Figure 7 illustrates the differences between data spaces and data platforms, the latter which have existed for some time. In fact, a data platform enables the expansion of business and/or

44 See https://data-intermediation.eu/en/data-intermediation/

improvement of the user experience. It centralizes the collection of various data, optimizes storage, and manages processing to make the data usable across the organization. Data spaces differ from data platforms by offering the possibility of scaling up within a domain and even beyond, as Gaia-X ensures their interoperability.

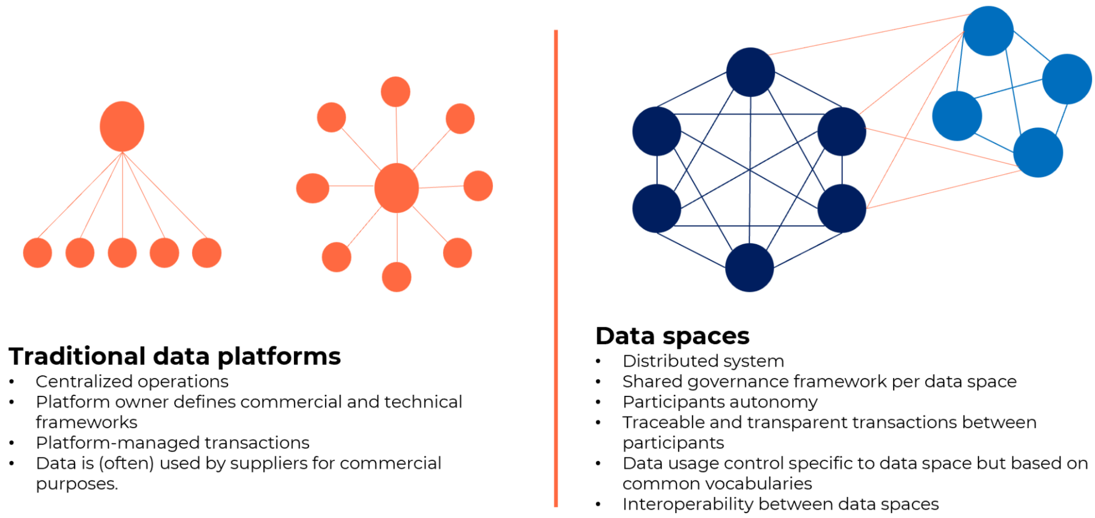

Figure 7. Comparison between a data space and a data platform (source: Hub France Gaia-X)

4. European Initiatives providing tools in favor of interoperability

This chapter presents major European initiatives that supply technical building blocks, standards, and governance models necessary to interoperate LDTs and data spaces. It highlights initiatives like FIWARE, the LDT Toolbox, SIMPL Middleware, MIMs Plus, and DS4SSCC as foundational resources for pilot projects. These initiatives enable the operational implementation of platforms and data spaces that allow them to be linked together.

More initiatives in the following areas are presented in the [LDT4SSC Knowledge Hub | Smart Communities Ecosystem] page.

1. **Data spaces**
    - DS4SSCC –Data Spaces for Smart and Sustainable Cities and Communities
    - SIMPL
    - Gaia-X
2. **AI for Smart Communities**
    - CitCom.ai
    - CitComTEF
    - Big Data Test Infrastructure (BDTI)
    - DeployAI –AI Deployment Platform for Smart Cities and Local Digital Twins
3. **Local Digital Twins**
    - European Local Digital Twins Toolbox
    - DUET –Digital Urban European Twins
4. **Interoperability & MIMs Plus**
    - FIWARE
    - MIMs and MIMs Plus
    - Interoperability Test Bed (ITB)
5. **Citiverse**
    - LDT CitiVERSE EDIC
    - X-Cite –Cross-Domain Digital Twin Ecosystem for Smart Cities
    - 3Dxverse –3D Digital Twin Platform for Smart Cities and Industrial Applications
6. **Cities Network and Supporting Actions**
    - NetZeroCities
    - Living-in.EU Community
    - Open Data Institute (ODI)

This selection of initiative within the LDT4SSC ecosystem, as described in the project's Knowledge Hub, will evolve throughout the project.

In the following sections, we will further describe some of these initiatives::

- 4.1 FIWARE (Interoperability & MIMs Plus)
- 4.2 The EU Local Digital Twin Toolbox (Local Digital Twins)
- 4.3 SIMPL(Data spaces)
- 4.4 Gaia-X (Data spaces)
- 4.5 MIMs Plus (Interoperability & MIMs Plus)

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4.1 FIWARE

FIWARE is an open European initiative that has transformed into a foundation. It **maintains a set of standard** (open-source) **software components** that enable the **construction of interoperable, scalable, and intelligent digital systems**. It was created to **avoid technological fragmentation in the development of digital solutions**, particularly in cities, regions, industry, and the environment.

One of the core components of FIWARE is based on the **concept of context information management**: this means that **data**, regardless of its type or source (IoT, business databases, sensors, citizens, etc.), is **represented and processed in a unified format called NGSI-LD**, a standardised specification at the European level.

To ensure semantic interoperability across domains, FIWARE also drives the **Smart Data Models**[45] initiative, a global open library of harmonised NGSI-LD data models, co-created with partners such as Open & Agile Smart Cities & Communities (OASC) and India Urban Data Exchange (IUDX), and widely adopted in smart city and industry projects.

A typical FIWARE platform includes:

- A **Context Broker** (such as Orion-LD[46], Scorpio[47], or Stellio[48]), which centralizes contextual data in real time;
- **IoT connectors** (FIWARE IoT Agents[49]) to connect existing sensors and systems;
- **Components for analysis**, visualisation, storage, authentication and authorization.

FIWARE does not offer a single "turnkey" platform, but rather a **modular architecture framework** from which each community can draw according to its needs. It thus promotes **solution portability, component reuse, and built-in interoperability**.

Many cities in Europe, such as Saint-Quentin (France), Amsterdam (Netherlands), Perougia (Italy), and Valencia (Spain), are already relying on FIWARE to structure their digital infrastructures.

4.2 The Local Digital Twin Toolbox

As part of ongoing efforts to **standardize digital solutions**, the **European Commission, through the Living-in.EU initiative**, has launched the Local Digital Twin (LDT) Toolbox. Its goal is to **enable local authorities**, regardless of their size or digital maturity, **to gradually build their local digital twin in a consistent and interoperable manner.**

The LDT Toolbox will offer:

- A **reference architecture** (based in particular on FIWARE and NGSI-LD, but also on the results of the SIMPL project for the interconnection with data spaces) to ensure the interoperability of systems and data;
- **Common data models**, such as Smart Data Models[50];

[45] See https://smartdatamodels.org
[46] See https://github.com/FIWARE/context.Orion-LD
[47] See https://github.com/ScorpioBroker/ScorpioBroker
[48] See https://github.com/stellio-hub/stellio-context-broker
[49] See https://fiware-tutorials.readthedocs.io/en/latest/iot-agent.html
50 https://smartdatamodels.org/

- **Methodological guides** to support governance, prioritisation of use cases, and legal structuring;
- **Reusable software tools** (visualisation engines, simulators, dashboards, etc.);
- **Feedback** from pioneering regions, enabling other local authorities to benefit from already established pathways.

The LDT Toolbox is still under active development. Although its release is expected in the coming months, no components are available at the time of this Technical Landscape Report.

4.2.1 Toolbox Architecture (work in progress)

The LDT Toolbox comprises a number of components and can be divided into three categories:

- **Tools**: Domain-agnostic software that provides distinct, coherent capabilities to build or extend a local digital twin. Deployment and management are the responsibility of each user.
- **Sites**: Centralised services for sharing resources among LDT Toolbox users. These are deployed and managed by the EU.
- **Assets**: Packaged datasets, algorithms or models, available via a marketplace and designed for their use with the Toolbox's tools.

According to this definition, the LDT Toolbox is structured in the following sites, tools and assets.

Figure 8 illustrates the components of the LDT Toolbox, organised by functional layers and aligned with the Minimal Interoperability Mechanisms (MIMs) Plus.

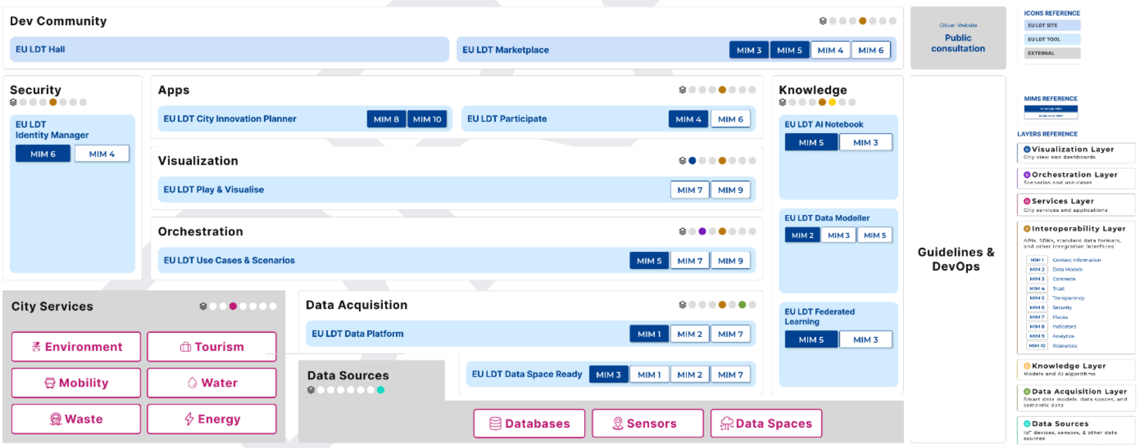

Figure 8. LDT Toolbox solutions structure with layers and MIMs Plus

A. Sites (work in progress)

Site 1. EU LDT Hall

The Hall is the public front door to the Toolbox: a project website where cities and stakeholders download releases, find learning materials, and connect to the developer and user communities. It runs as a small site of its own (project web + database) but leans on existing Commission services, such as the Joinup[51] for releases and community, Code

[51] https://interoperable-europe.ec.europa.eu/collection/ldttoolbox

Europa for code[52], EU Survey for surveys, and EU Login for authentication. Admins can publish pages, news, events, and surveys from here.

NB: The Hall will serve as the central web portal of the LDT Toolbox, where users will find learning materials, examples, tutorials, and links to the Marketplace and other related resources. It is not available yet.

Site 2. EU LDT Marketplace

The Marketplace is the exchange hub for assets, datasets, models, algorithms, synthetic data generators, enabling both open-sharing and commercial transactions. It exposes catalog, ordering, revenue, SLA/licensing, and reputation features, with federation support so that multiple marketplaces can interoperate (Gaia-X-aligned). Under the hood, it consists of a web app + backend + database, integrating external services for payments and EU Login, along with a DOME Marketplace with PostgreSQL as the baseline stack.

NB: The LDT Toolbox is still under active development. Although its release is expected in 2026, no components are available at the time of this Technical Landscape Report.

B. Tools (work in progress)

Tool 1. EU LDT Play & Visualize

Play & Visualize is the interactive 2D/3D front-end for the digital twin. It connects to Use Cases & Scenarios and the Data Platform to render near-real-time, synthetic, and forecast layers; and it feeds multimedia snippets to Participate to help citizens understand proposals. The deployable setup is simple (frontend, backend, database) and supports OGC/WMS/WFS standards, 2D/3D maps, streaming/batch/static sources, XR/WebXR, and “what-if” outputs. Candidate render/visual libraries include Babylon.js, D3.js, Plotly.js, deck.gl, MapLibre, and kepler.gl.

Tool 2. EU LDT Use Cases & Scenarios

This is the heart of the Toolbox where technicians define Cases, configure Scenarios, and run Experiments; orchestrate data flows; and publish results and context to other tools. The solution includes an API Gateway, a WebApp + API for Case/Scenario management, an event-based publishing service, and a data-workflow/orchestration layer (batch & stream processors plus harmonisation). It exposes geospatial/analytical outputs via APIs, is compatible with SIMPL mechanisms, and provides transparency/explicability hooks for AI/ML.

Tool 3. EU LDT Participate

Participate is the citizen-engagement portal: consultations, discussions, videoconferencing, and engagement analytics. The deployment comprises a citizen portal (web app + worker + DB + file storage), a video service, analytics (tracker + DB), and integrations with EU Login and the city’s email server. It implements strong GDPR-centric personal-data controls. The baseline component choices include Decidim (participation), Jitsi Meet (video), Matomo (analytics), Grafana (dashboards), and PostgreSQL.

[52] https://code.europa.eu/info/about

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Tool 4. EU LDT City Innovation Planner

City Innovation Planner lets a city set goals, define/track KPIs (aligned with United for Smart and Sustainable Cities (U4SSC)[53]), monitor progress versus real KPIs from the Data Platform, and compare simulated impacts from Use Cases & Scenarios (including Return On Investment (ROI) estimates). It's delivered as a standard three-tier app (frontend, backend, database) and communicates with Identity Management, Use Cases & Scenarios, and the Data Platform. The User Interface (UI) relies on charting libraries such as D3.js and Plotly.js with PostgreSQL for persistence.

Tool 5. EU LDT Identity Management

Identity Management is the central gatekeeper for users, clients, scopes, and permissions across the Toolbox. Its "identity service" handles identity, user, and access control; the "asset service" registers assets participating in the ecosystem. It federates with a city directory if present and supports fine-grained authorization, user federation, and strong authentication -Keycloak-class capabilities. It also respects GDPR rights for staff and manages ontologies/schemas aligned to Smart Data Models.

Tool 6. EU LDT Data Platform

The Data Platform is where cities ingest and standardize data from databases and sensors, giving it NGSI-LD context and making it queryable for the rest of the Toolbox. The solution includes a context broker, IoT agent manager, IoT edge device manager, query engine, and data-replication service, backed by stores for time-series, device configuration, and context. It supports synthetic data alongside real data for simulations and provides event-driven replication/versioning and alerting. Typical building blocks include PostgreSQL, FIWARE IoT Devices API and Services (IDAS) agents, MongoDB, and edge orchestrators (MicroShift/KubeEdge).

Tool 7. EU LDT Data Space Ready

Data Space Ready connects the city to external data spaces and governs secure inbound and outbound data exchange. It includes an authenticator supporting SIOPv2[54] and OpenID for Verifiable Credentials flows[55] (OID4VP for presentation and OID4VCI for issuance) with managed trusted-issuer lists; a policy manager implementing Attribute-Based Access Control (ABAC) with PAP, PDP, PIP, PEP, and PRP; a contract manager aligned with TM Forum Open APIs; and a connector registry. It integrates with the city's IAM to issue and validate verifiable credentials and federates with the European Digital Identity (EUDI) Wallet. The FIWARE Data Space Connector serves as a reference connector. Alternatively, Data Space Ready plans to support Eclipse Dataspace Components (EDC) as connector with Eclipse DCP (Decentralized Claims Protocol)[56] and DSP (Dataspace Protocol)[57].

Tool 8. EU LDT AI Notebook

AI Notebook streamlines the integration of models/algorithms for the Toolbox. It gives AI developers a Software Development Kit (SDK) and interfaces for execution modes, orchestration, and concurrency between models; wraps assets for Marketplace publication with documentation/templates for transparency; and integrates with Federated Learning for

[53] See https://u4ssc.itu.int/
[54] See https://github.com/openid/SIOPv2
[55] See https://openid.net/sg/openid4vc/
[56] See https://projects.eclipse.org/projects/technology.dataspace-dcp
[57] See https://internationaldataspaces.org/offers/dataspace-protocol

decentralised training. Kubeflow or MLflow are the reference foundations evaluated for this environment.

Tool 9. EU LDT Data Modeller

Data Modeller helps create synthetic data generators (manual schema design or auto-modelling from sample data) that match Smart Data Models and are compatible with the Data Platform entities. It packages generators as Marketplace assets, so cities can simulate scenarios without exposing real data. The solution comprises a UI, a backend packager, and an auto-modeller; “Synth” is a candidate engine for high-quality synthetic data.

Tool 10. EU LDT Federated Learning

Federated Learning enables decentralised training where data stays local. A lightweight client runs on each participating node (installed by the data holder), and training is coordinated from the AI Notebook (federated server). This accelerates training, scales across nodes, and preserves sovereignty/privacy. Flower is the reference framework selected for multi-framework flexibility.

C. Assets

Asset 1. EU Buildings Database

The Buildings Database is a pan-EU geospatial asset (discoverable in the Marketplace) used by visualization and modelling tools. It fuses multiple open datasets into a homogeneous, WGS84-based entity model (building/tile) with fields like geometry, occupants, cost, number of buildings, and constructive elements (GEM taxonomy[58]). Coverage spans all 27 EU countries, with partial downloads supported and Open Database License (ODbL) licensing.

4.2.2 Operational Workflow Across the LDT Toolbox

The following section highlights a local authority’s team’s journey in the creation of a Local Digital Twin with the LDT Toolbox, from start to finish.

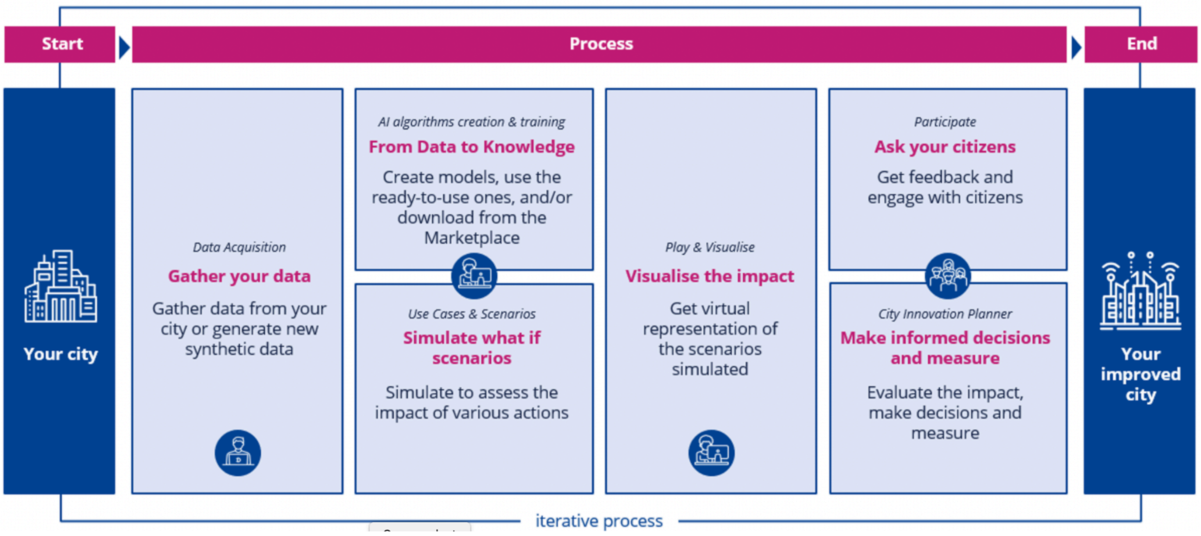

Figure 9. Common operational workflow of the LDT Toolbox

58 See https://github.com/gem/gem_taxonomy

As such, the process is made of several steps: 1) Gather data / Data Acquisition, and potentially generate new data; 2) Create models / AI algorithms, and possibly download others from marketplaces; 3) Generate "what-if" scenarios to try and assess the impact of various actions in the future for the local authority; 4) Create dashboards and other virtual representations to visualise the impacts of the Local Digital Twin being created; 5) Involve the end-user, i.e. the citizens, engage them and get feedback; 6) Take all of the latter into consideration in a smarter, better decision-making process for an improved city. All these steps are part of an iterative process, and do not necessarily need to be followed in order for one to obtain a satisfying LDT result. To provide an overview, Figure 9 visually presents this workflow.

A. Local Authority team journey

1) Discover & get access

Teams land on **EU LDT Hall** to grab releases, documentation, and learning materials; Hall also links the code repositories and communities (Joinup, Code Europa, EU Survey, EU Login).

The City System Administrator sets up users/clients and access levels in **Identity Management** (Keycloak-based), and registers assets so that other tools can see them. This is the central place the rest of the toolbox calls to validate permissions.

2) Prepare the city's data backbone

The City Database Administrator connects live and historical sources in the Data Platform: configure IoT agents and/or edge nodes, stand up the NGSI-LD context broker and time-series storage, and expose unified querying. This platform supplies data to **Use Cases & Scenarios** for simulations and to **Play & Visualise** for maps/2D/3D/XR.

If data must flow in/out of external organisations, the admin configures **Data Space Ready** to handle authentication with verifiable credentials, ABAC policy decisions, and contract management-integrating with Identity Management and the Data Platform.

Optionally, the admin fetches baseline assets like the **EU Buildings Database** from the **Marketplace** to get consistent geospatial building tiles/entities for visualisation and computation.

3) Plan and define what to simulate

The team designs the initiative in **Use Cases & Scenarios**: capture the use case, define scenarios, wire data flows, and orchestrate components. Under the hood, this tool uses an API gateway + web app, event-based publishing and a workflow/orchestration tier; a message broker enables pub/sub between services.

It can harmonise inputs (e.g., via a Data Flow/Harmonisation layer) and publish events for batch/stream processing; Kafka-style pub/sub and graphical data mashup capabilities are part of the architectural approach.

4) Bring or build the intelligence

AI developers create algorithms/models in **AI Notebook** using the common abstraction/SDK; they can run models synchronously, asynchronously, in real-time, batch, scheduled, event-triggered, and even deploy to cloud/edge. When ready, they package with templates and publish as assets to the **Marketplace**.

If data is scarce or privacy-sensitive, devs craft synthetic data generators with **Data Modeller** (manual schema or auto-modelling from sample data) and publish those generators as assets. These generators are built to align with Smart Data Models and to plug into the Data Platform like any other source.

When training must stay distributed, they coordinate training rounds through **Federated Learning** (clients on partner nodes; server side coordinated from AI Notebook). Flower-based FL supports multiple ML frameworks and reports training metrics, while keeping raw data local.

5) Run simulations and visualise

Use Cases & Scenarios invokes the selected models (via the AI Notebook abstraction) and streams/pulls data from the Data Platform (real + synthetic) to execute scenarios.

Play & Visualise renders the twin (maps/2D/3D/XR) by consuming scenario outputs from Use Cases & Scenarios and live/historic context from the Data Platform; it also produces multimedia snippets that **Participate** can embed for citizen-facing explainers.

6) Engage citizens, ensure transparency

Participate hosts public threads, events, meetings (Jitsi), polls and surveys, with analytics (Matomo/Grafana). It automatically pulls: (1) multimedia from **Play & Visualise**; (2) scenario details + “what data/algorithms/models were used” from **Use Cases & Scenarios**; to meet transparency provisions (AI Act-aligned disclosures) and close the feedback loop.

7) Decide and monitor outcomes

City Innovation Planner tracks maturity/KPIs, compares simulated vs observed outcomes (from Use Cases & Scenarios and the Data Platform), and keeps goals aligned with standards. This becomes the city’s scoreboard for progress.

8) Share, scale, and reuse

Publish datasets, models, synthetic generators, or complete “scenario packs” to the **Marketplace** for other cities; exchange governed data through **Data Space Ready** when collaboration requires inter-org policies and contracts. Identity Management remains the single source for access control across the ecosystem.

B. Citizen & external stakeholder journey

Citizens arrive at **Participate**, sign in (EU Login[59]/ Open ID Connect[60]), browse proposals, watch embedded 2D/3D/XR explainers from **Play & Visualise**, review “what models/datasets were used” pulled from **Use Cases & Scenarios**, and submit feedback via polls/surveys/threads or join Jitsi town-halls. Their engagement is measured and can be exported, while scenario truths stay managed in Use Cases & Scenarios.

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59 See https://wikis.ec.europa.eu/spaces/NAITDOC/pages/33529367/EU+Login+-+European+Commission+Authentication+Service

60 See https://openid.net/developers/how-connect-works/

External parties can inspect the relevant assets on the **Marketplace** (the same ones referenced in Participate) and, where appropriate, connect via **Data Space Ready** under agreed policies.

C. How the pieces fit together

Having outlined the local authority and citizen journeys, this subsection introduces how the toolbox operates as a single, coherent system. Five cross-cutting elements make the pieces fit and keep people, data, and processes aligned end-to-end: identity first (who/what is allowed to act), data flows (how information is ingested, modeled, stored, and queried across real and synthetic data), events/orchestration (how pipelines are coordinated and workloads triggered), the transparency loop (how stakeholders see what's being simulated and why), and governed sharing (how inter-organizational exchange is secured and contracted). Taken together, these elements transform standalone tools into a secure, traceable, and repeatable LDT. The bullets below summarise each element and how they interlock in practice.

- **Identity first**: every tool calls Identity Management to validate users/clients and scopes (Zero-Trust, MIM-6, GDPR/MIM-4). It also provides an asset registry so datasets and APIs/streams, algorithms/models (AI Notebook), synthetic data generators (Data Modeller), and other Marketplace artefacts are registered and discoverable across tools. Registration enables cross-tool search, rich metadata, lineage/versioning, policy-based ownership/access, and full auditability for reuse.
- **Data flows**: Data Platform is the city's backbone (ingestion, NGSI-LD context, storage, query, replication, events), serving Use Cases & Scenarios and Play & Visualise uniformly; synthetic data is stored and provided exactly like real data (labelled as synthetic).
- **Events/orchestration**: Use Cases & Scenarios orchestrates the pipeline and relies on a message broker + event-based publishing; batch/stream processors harmonise data for scenarios.
- **Transparency loop**: Participate consumes scenario + asset metadata from Use Cases & Scenarios and media from Play & Visualise, so citizens can see what's being simulated and why (AI Act-style transparency).
- **Governed sharing**: Data Space Ready enforces authentication with verifiable credentials and policy-based authorisation/contracting when data crosses organisational boundaries.

4.3 SIMPL Smart Middleware

Smart Middleware Platform (SIMPL) is a strategic building block for the interoperability of European data spaces. It is an initiative led by the **European Commission** as part of the **Digital Europe Program (DEP)**. It aims to provide an **open-source software infrastructure enabling the implementation of European data spaces**, ensuring a high level of interoperability, security, and sovereignty. As an intermediary platform (middleware), SIMPL **connects different data providers and consumers** while allowing each **player to retain control over their digital assets**. It thus constitutes a common technological foundation for deploying distributed and scalable architectures that comply with the principles of the European data strategy.

As shown in Figure 10, the SIMPL platform is based on a modular approach and consists of three complementary elements:

1. **SIMPL-Open** refers to the **open source technical platform**, composed of **reusable components for building or integrating interoperable data spaces**.
2. **SIMPL-Labs** offers a **test environment (sandbox) for developers**, project leaders, and administrations to experiment with **technological building blocks**, validate their interoperability, and refine their architecture.
3. Finally, **SIMPL-Live brings together pilot deployments in various strategic sectors** (health, mobility, public procurement, digital twins, etc.) in order **to test the solution** in concrete, multi-sector use cases.

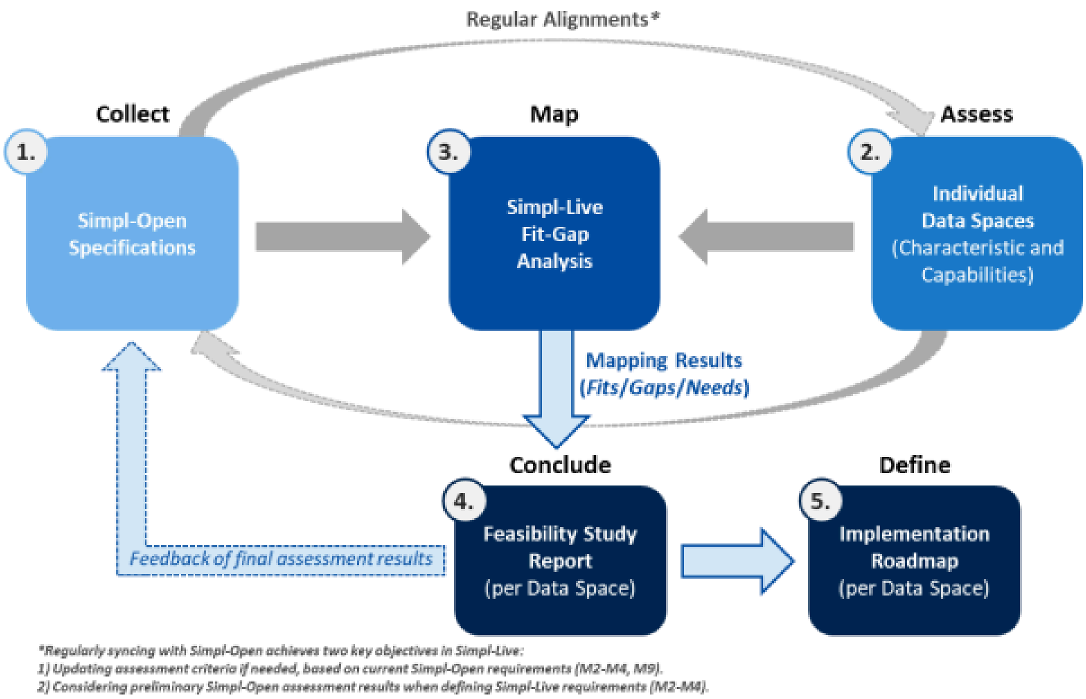

Figure 10. SIMPL-Live methodology[61]

Figure 11 illustrates how SIMPL Agents, i.e. a SIMPL Middleware Component, deployed in different participants of a data space enable interconnection and interoperability.

Indeed, SIMPL-Opens' unique value proposition is to cover the full landscape of a data space. As such, and as highlighted in Figure 5 (see *Figure 5*) for the basic structure and functioning of a data space, the latter becomes feasible in the context of SIMPL, allowing the interconnection of different actors, whether they be public or private, to exchange data and information.

The different capabilities of the SIMPL-Open software stack are described in more details below:

- **Reuse, develop, integrate:** SIMPL-Open:

[61] Feasibility Study Consolidated Report Simpl-Live (V1.2, 28/03/2025) - https://simpl-programme.ec.europa.eu/system/files/2025-06/Simpl-Live-Feasibility-Study-Report-%28Consolidated%29_Simpl_20250328_V1.2%28A%29.pdf

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- Identifies suitable existing components.
- Develops from scratch missing components.
- Integrates them to simplify the deployment and set up of a data space.

- **Engrained security:** The set-up of SIMPL-Open secure communication is part of the onboarding of new participants.

- **Flexibility through configuration:** Each data space can configure numerous elements, such as the rules for onboarding, the definition of identity attributes, the metadata required for publishing datasets/services, etc.

- **Inclusion of new types of providers:** SIMPL-Open also considers Infrastructure and Application providers, enabling providers to bundle infrastructure, application and datasets as they see the need.

- **Improved data sovereignty:** SIMPL-Open provides the possibility to define access policies, usage policies and contracts. SIMPL-Open also enables custom data sharing alternatives, as defined in the SIMPL architecture below (Figure 11) of a data space for example.

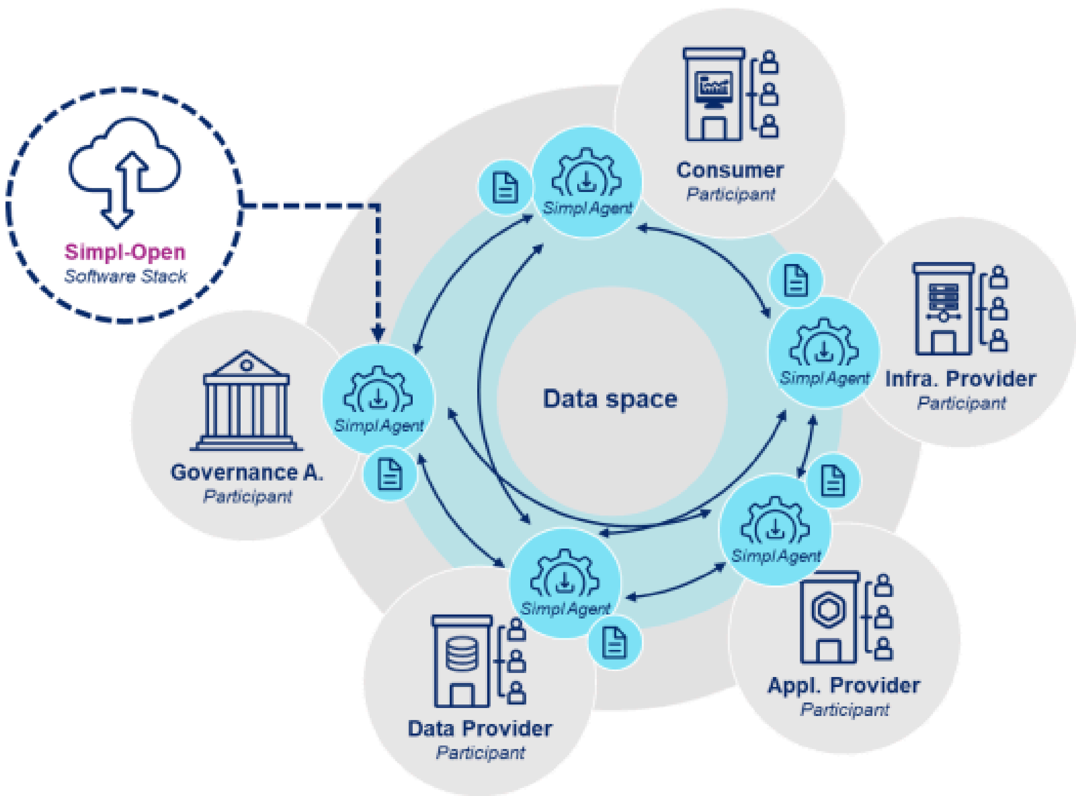

Figure 11. SIMPL-Open approach to cover the full landscape of a data space (source: SIMPL)[62]

Thanks to SIMPL, the interconnection and data exchanges of the participants to a data space is made possible as shown in Figure 11.

[62] See https://data-sharing-festival.net/wp-content/uploads/2024/12/Nicolas-Auricchio-Simpl.pdf

4.4 Gaia-X

Faced with the dependence on large digital platforms and fragmented systems, under initiatives from the European Union –and initially French and German Ministries for Economy– Gaia-X was created as a project to structure controlled, secure and interoperable data sharing aligned with European values about digital sovereignty.

Gaia-X is an international non-profit association that defines a framework of rules, standards and tools enabling different actors -public or private- to share data in a trusted environment. Each organisation retains control of its data within a common technical and legal framework that promotes interoperability, portability and transparency. For local authorities, Gaia-X provides a solid foundation for building sovereign data spaces.

Gaia-X brings together several hundred companies and institutes from around the world and, together with different members and organisations (mostly about standardisation), is in the process of **establishing a number of *de facto* standards for the interoperability of data spaces**. In particular, Gaia-X is establishing frameworks and specifications on the following topics:

- **Data exchange**, authorisation and consent management: W3C VC/VP, ODRL, DCATv3[63].
- **Identity management**: use of Decentralized IDentifiers (DID) (W3C standard), X509 and JOSE for the cryptographic chain.
- **Verifiable Credentials**: use of VC for services and participants (W3C Verifiable Credential, W3C SHACL and W3C SPARQL), OIDC4VC and OIDC4VP for VC exchanges.
- **Chain of trust** (ETSI TS 119 312[64] and European Blockchain Services Infrastructure (EBSI) APIs for Trust Anchors).

4.5 Minimum Interoperability Mechanisms (MIMs) Plus

Minimal Interoperability Mechanisms (MIMs) Plus are essential guidelines to deploy and evaluate the deployment of interoperable solutions in Europe. They emerged under the impetus of the **OASC** to **enable a minimal but sufficient level of interoperability of data, systems, and services, particularly in the context of smart city solutions**. By facilitating this minimum level, MIMs pave the way for the development of a **coherent global market** and collaboration focused on solutions, services, and data.

The MIMs are vendor- and technology-neutral, meaning that anyone can use them and integrate them into existing systems and offerings.

While the MIMs strive to enable a global/worldwide marketplace for data, systems and services, the MIMs Plus provides this for the European market. The Living-in.EU movement and its Technical Working Group is responsible for moving this work forward with the guidance of the OASC organisation to ensure that MIMs and MIMs plus remain in dialogue.

MIMs can be useful in several scenarios:

[63] see Glossary for more
[64] https://www.etsi.org/deliver/etsi_ts/119300_119399/119312/01.04.03_60/ts_119312v010403p.pdf

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1. **Software change:** *For example, an administration may want to acquire a new customer relationship management (CRM) tool. It currently uses SalesForce, but to better integrate with its Office suite, it wants to switch to Microsoft Dynamics CRM. In order to retain all historical data, it must be able to access this data and import it into Dynamics. This may require numerous transformations of the data from SalesForce and its mapping to Microsoft Dynamics. However, if the requirements defined in the MIM on data models are met, the data models of both systems will be described correctly and this work will be minimised.*

2. **Connection between one platform/software and another:** *For example, a local authority may want to receive notifications whenever air quality falls below a certain threshold. To do this, it needs to connect to the National Environmental Agency. If the ICT infrastructure of these agencies is based on MIMs, they will be able to easily subscribe to notifications using a generic API.*

3. **Creating and using interoperable solutions:** *Let's say a startup is developing a mobility solution. To do this, it wants to access real-time open data from parking providers in different cities. In general, it must implement an integration for each parking provider and possibly organize numerous meetings with their respective technical teams to discuss formats, access control, etc. However, if these parking providers comply with MIMs, this information should be accessible in a machine-readable format and the number of integrations would be limited to certain common data models.*

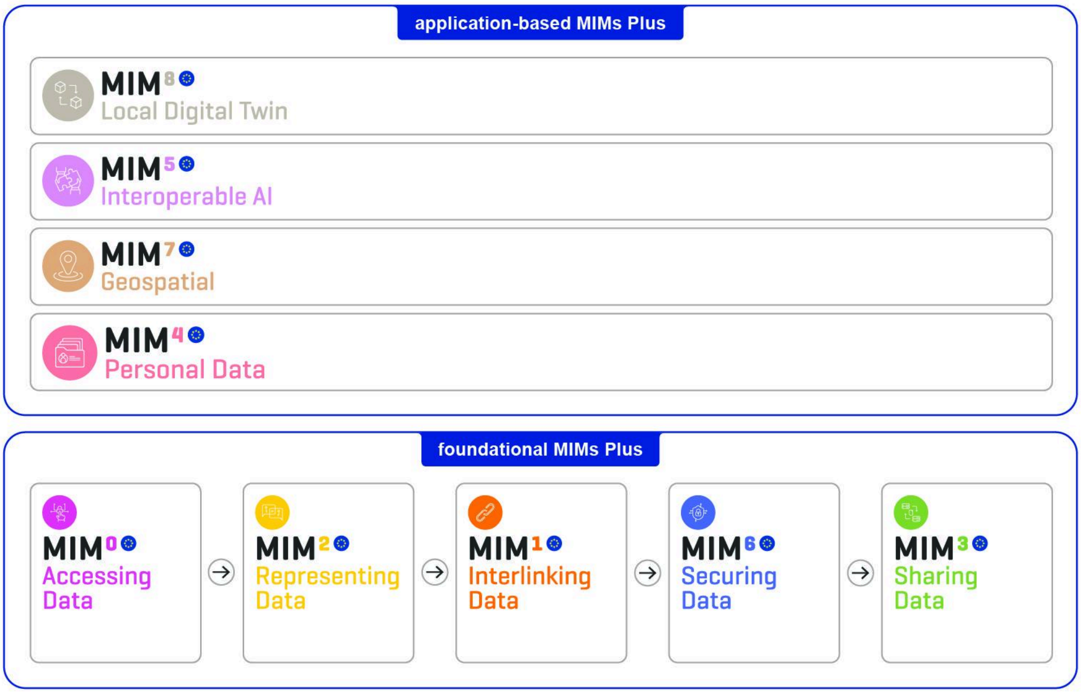

Figure 12. MIMs' Plus Framework Overview

One of the MIMs Plus' **advantages** is their **flexibility of adoption**: each local authority can start with one or two priority MIMs, depending on its use cases, and then gradually increase their maturity. They are **not closed standards, but evolving recommendations**, co-developed with local authorities and aligned with European frameworks.

Each MIM identifies an area in which interoperable mechanisms need to be put in place. At the time of publication of this report, the MIMs' framework is at version 8 and distinguishes between two main categories:

1. **Foundational MIMs**, which provide essential functionality for data interoperability within a city's data ecosystem;
2. **Application-Specific MIMs**, which will enhance the functionality of the data ecosystem by introducing interoperability in specific application areas.

The different existing MIMs are shown in Figure 12 and described in Table 1. The MIMs 8, 5, 7 and 4 are what are called Application-Specific MIMs, while the other MIMs are the Foundational MIMs.

The following table provides an overview of the 9 MIMs Plus and a description for each of them:

#	Application area	Description
MIM0	Accessing Data	Ensure that data is accessible across an organisation's various systems via interoperable APIs.
MIM1	Interlinking Data	Ensure that data sources can be interconnected with each other based on their contextual relationships in an interoperable manner, to enable better interpretation and use of data.
MIM2	Representing Data	Ensure that data can be used more effectively within an organisation by representing it using interoperable data formats based on standards.
MIM3	Exchanging Data	Ensure that data can be effectively discovered by data users within an organisation and stakeholders in a broader data ecosystem and exchanged interoperably to enable data reuse and value creation by others.
MIM4	Personal Data	Enable individuals to easily manage their data so that it can be used to achieve the results they want, both for themselves and their community, without compromising confidentiality.
MIM5	Interoperable AI	Work in progress.
MIM6	Securing data	Ensure that data is properly secured and protected within a data ecosystem (in storage or in transit) in an interoperable manner.

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MIM7	Geolocation	Provide minimal interoperability mechanisms related to geospatial data to address the challenge cities and communities face in integrating and transferring data between internal and external Information Technology (IT) systems. It also takes into account the fact that spatial resources must be accessible as linked data by many IT and IoT systems over a long period of time, hence the crucial role of using persistent identifiers.
MIM8	LDT	To ensure Local (/Urban) Digital Twins can communicate with other data ecosystems, can scale up and they can integrate new data sets, services and components easily.

Table 13. Overview of the nine MIMs Plus

All the MIMs have the same standardised structure (based on ITU standard Y.4505, formerly known as Y.MIM), so the documentation for any MIM must cover the following content:

- Objectives
- Capabilities
- Requirements
- Mechanisms
- Interoperability guidance
- Conformance and compliance testing

In addition, MIM documentation may include informative content concerning, as shown in Figure 13:

- Relevance to public policy
- Guidelines for public procurement
- Implementation guidelines

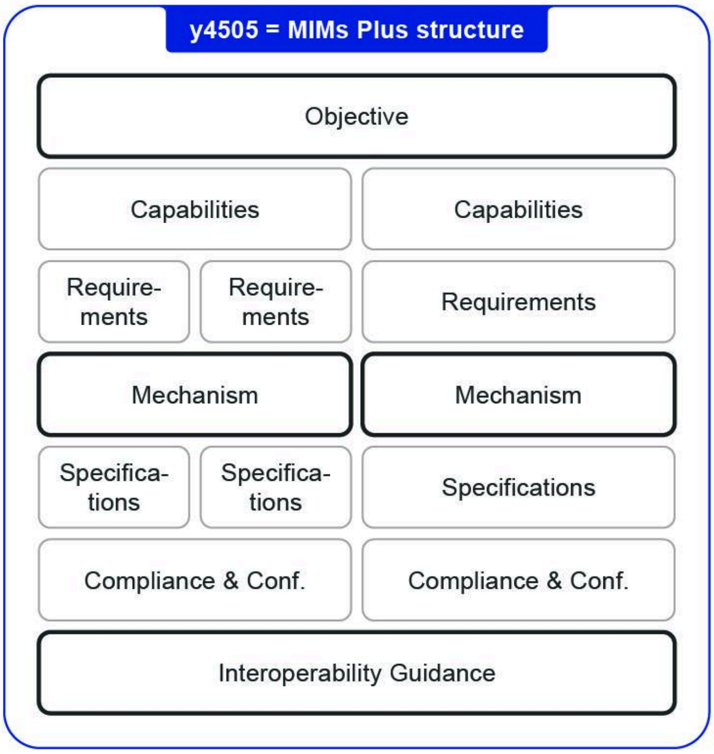

Figure 13. Y.4505 structure of MIMs Plus[65]

On July 17, 2024, the Open and Agile Smart Cities (OASC) association announced that the United Nations International Telecommunication Union (ITU) Study Group 20 (SG20) had officially adopted by consensus the global "Y.4505" standard for minimum interoperability. This important milestone represents a major step forward in enabling cities and communities around the world to achieve their goals for an inclusive, sustainable, and prosperous future through digital technologies.

In order to be applicable, these MIMs refer to multiple norms and standards that enable the deployment of robust, interoperable data infrastructures and the testing of technical choices. This is because there are multiple technical solutions that can be chosen to ensure compatibility with the MIMs and the standards described therein (see 5.1).

For example, the NGSI-LD standard is very useful for implementing MIM0 and MIM1.

[65] https://oascities.org/minimal-interoperability-mechanisms/

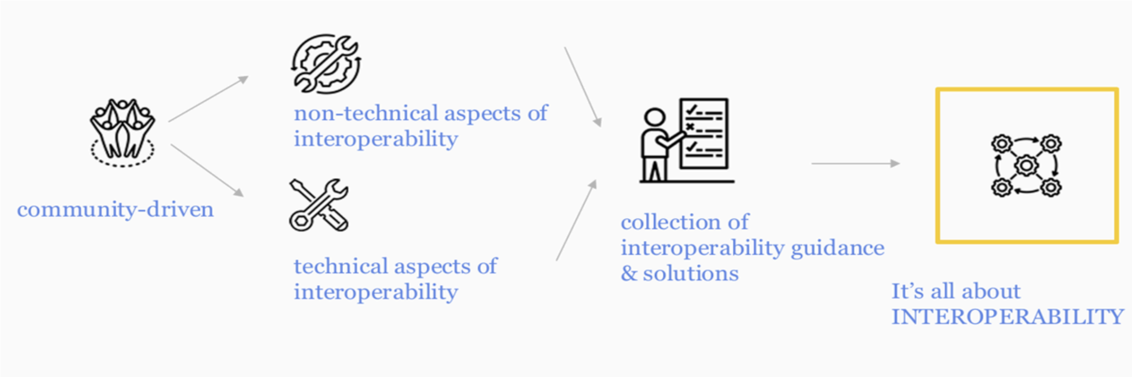

Figure 14. OASCs approach to interoperability in building MIMs

Figure 14 presents the MIMs Plus approach to interoperability, which combines technical and non-technical aspects. These two aspects are grouped together with a set of recommendations and references to interoperability solutions, integrated into the MIMs Plus.

In practice, when a stakeholder wishes to make progress in terms of interoperability, it is necessary to take into account technical and semantic aspects, as well as legal and organizational aspects, in order to achieve this.

5. Technical solutions enabling interoperability

This chapter delves into the specific technical standards, identity and trust frameworks, knowledge modeling practices, and maturity levels of solutions that underpin interoperable LDTs and data spaces. It offers practical guidance on implementing interoperability across legal, organizational, semantic, and technical dimensions.

All of the components presented below are useful for building a data management platform, whether you want to create (or participate in) a data space, a local data management platform, a digital twin, or interconnect them (6. Interconnection of LDTs (WS1)). For instance, creating a data space does not necessarily require the integration of context brokers, but when **creating a digital twin the integration of a context broker is a good solution** (see *6.2.3 Interconnection of Digital Twins* for more)**.**

5.1 Technical components

The following sections presents a non-exhaustive list of standards, frameworks, protocols and technical solutions, and implementations that can be used to achieve interoperability. Most of these can be found in Figure 15, which depicts the coverage of the European Interoperability Framework (EIF) by these.

As this Technical Landscape Report is an initial work in the LDT4SSC project it will be completed by the technical resources that will be gathered and produced for pilots to facilitate their projects in Task 3.3. The list of aftermentioned standards, frameworks, protocols and technical solutions, and implementations in this section will be completed.

5.1.1 Standards

- **European Committee for Standardization (CEN)/ European Committee for Electrotechnical Standardization (CENELEC) CEN Workshop Agreement (CWA) 18125:2024 -Trusted Data Transaction (TDT)**[66]: terminology, concepts and mechanisms for trusted data transactions (see *CEN-CENELEC* for more).
- **ETSI TC Data: European standardization request for data spaces is now official**
- **ETSI NGSI-LD: GS CIM 009 (v1.9.1, 2025)** + NGSI-LD portal. ETSI
- **OGC API Features**: modern geospatial API standard (OGC catalog) (see *ogcapi.ogc.org* for more).
- **IFC (openBIM)**: bSI page & ISO 16739-1:2024 status (see *buildingSMART International* for more).
- **ISO 10303 STEP**: e.g., AP242:2025 (Managed model-based 3D) (see *ISO* for more).
- **OpenAPI 3.1 + JSON Schema 2020-12**: API contract & JSON schemas (see *OpenAPI Initiative Publications* for more) for interface contracts and versioning.
- **Exchange & transport (EU/OASIS/IETF)**: eDelivery/AS4 for B2B/B2G messaging; SFTP (fallback); eventing (AMQP/MQTT) when needed.
- **Identity & trust** (electronic Identification, Authentication and Trust Services **(eIDAS)/ETSI + profiles)**: eID/eSignature/eSeal/timestamp (ETSI EN 319 xxx)

[66] TDT CWA is a pre-standardisation process, now being addressed by CEN JTC25. It defines requirements for trust framework (including for example Gaia-X or iShare) and interoperability.

- **Resource Description Framework (RDF)** for data interchange on the Web (See W3C for more)
- **Linked Data Event Streams (LDES)** (See Linked Data Event Streams)
- Domain ontology's **Internationalized Resource Identifier (IRI)** to identify resources.

5.1.2 Frameworks

- **Gaia-X Trust Framework[67]:** trust rules and federation guidance used by many European data spaces (see *docs.gaia-x.eu* for more).
- **iSHARE Trust Framework:** a cross-sector trust framework enabling organisations to share data in a legally- and technically- interoperable way.

5.1.3 Protocols

- **Dataspace Protocol (DSP)[68]**: a protocol used across many data spaces; official overview and the current spec (see *International Data Spaces* for more).
- **Open Data Protocol** (OData).
- SSH File Transfer Protocol (SFTP).
- **Hyper Text Transfer Protocol Secure (HTTPs)**

5.1.4 Technical solutions / Implementations

- **NGSI-LD context brokers**: **Stellio, Orion-LD** and **Scorpio** OSS implementations (see *Stellio* , Orion-LD, Scorpio for more).
- **Data Catalog Vocabulary (DCAT)** - Version 3: RDF vocabulary (see *W3C* for more) and the DCAT Application Profile for data portals (DCAT-AP) the specification based on DCAT.

A. Identity & Trust

- **OAuth 2.0 (RFC 6749)** & **OpenID Connect Core 1.0**: identity/authorisation foundation for APIs (see *IETF Datatracker* for more).
- **OpenID4VP**: presenting verifiable credentials (e.g., wallet flows) (see *openid.net* for more).
- **World Wide Web Consortium (W3C) Verifiable Credentials v2.0**: data model for credentials (see *W3C* for more).
- **W3C Open Digital Rights Language (ODRL)** (Information Model) + **Profile Best Practices**: machine-readable policies/licences (see *W3C* for more).

[67] Gaia-X is a trust framework, a set of label mechanisms (for sovereignty / cloud services) and a set of specifications (for identity, data exchange...).

[68] DSP is not an interoperability protocol as it is one protocol. In addition, different EDC implementations are not necessarily interoperable, even though they implement DSP, if they don't use a common trust framework.

B. Data space

- **Eclipse Dataspace Components (EDC)[69] CE by Sovity[70]:** ready-to-run EDC distribution (see *GitHub* for more).
- **SIMPL-Open** provides open source agents and a framework for realising a data space as well as the federation of existing data spaces (see SIMPL's project page for more information)
- **EDC[71] connectors**: open-source connector framework implementing the Dataspace Protocol; docs and project page (see *EDC* for more).
- **FIWARE Data Space Connector (FDSC)[72]**: FIWARE's connector suite; GitHub repo (includes a minimal viable data space deployment). Overview deck available (see *GitHub* for more).

C. Data Exchange Solutions

- **Dawex Data Exchange** (governance, trust, orchestration, catalog, data transactions, traceability). dawex.com

5.2 Maturity of the technical solutions

In the following section, we will present the readiness of various standards and technologies, distinguishing among mature, partially-developed, and emerging solutions. It highlights gaps and ongoing development efforts, particularly noting the early-stage status of the SIMPL platform and LDT Toolbox.

Figure 15 provides an overview of the different levels of interoperability required for data exchange among systems, organised around the following layers: **organisational, technical, legal, and semantic**. Each level is associated with a selection of standards, **frameworks, protocols, and technological solutions** that ensure interoperability.

This diagram follows a slightly different framework compared to the EIF's but they are substantially aligned in what they mean to describe. The main difference is the following: the Legal layer is separated into two subsections, that are respectively Policy (covering legal aspects, in the sense of compliance ones) and Contractual (legal considerations when it comes to B2B contractualisation for data transactions for example). The Figure further includes several initiatives and reference frameworks that are here classified according to their degree of maturity:

[69] EDC Connectors (and more generally connectors) are not Data Exchange platforms or solutions. They are (important) parts of Data Spaces, but, in itself, are not enough to build a data exchange / data space.

[70] Organisation developing the components. See https://sovity.de/en/sovity-en/

[71] EDC is a framework for building the same data space parts (including EDC connectors, which implement DSP protocol and lack a trust framework).

[72] FIWARE Data Space Connector is the implementation of a connector, which implements DSP protocol, but also the trust layer of Gaia-X.

- **Mature *de-jure* and *de-facto* standards:** the Gaia-X Trust Framework (i.e. a set of rules providing common governance and basic levels of interoperability)[73], the Eclipse Dataspace Protocol[74], identification protocols (OpenID, OAuth2, etc.), ODRL for digital rights management, and standards such as NGSI-LD for semantics.
- **Partial or developing solutions:** the CEN Trusted Data Transaction (TDT) standard, industry standards such as OpenBIM or STEP.

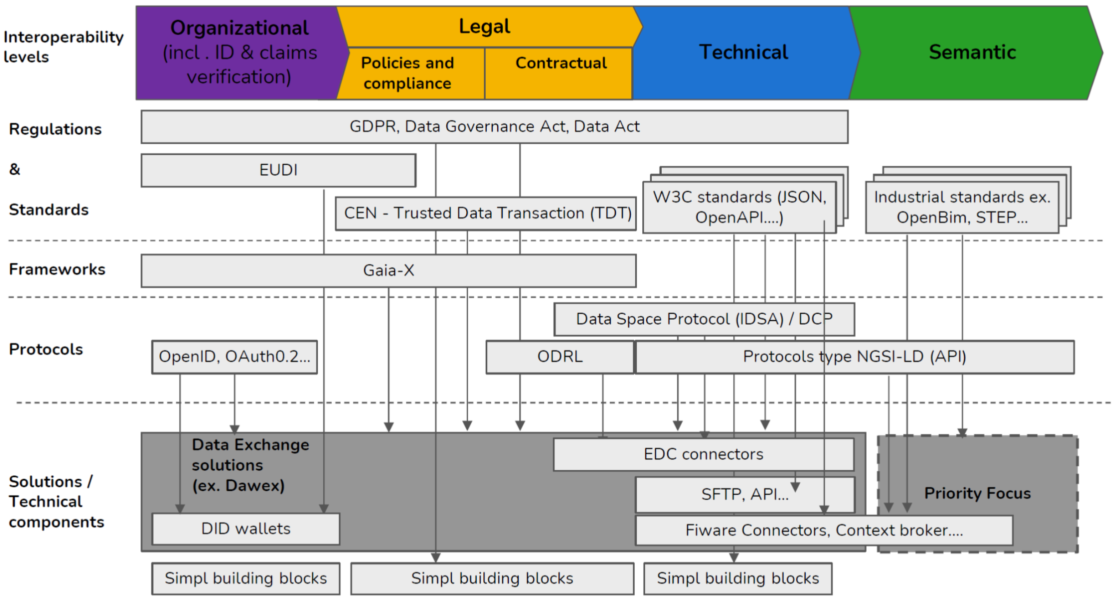

Figure 15. Coverage of interoperability framework by regulations, standards, frameworks, protocols and technical components

These elements act as bridges between the requirements of different levels, facilitating interoperability. As such, they translate standards into concrete operational tools or platforms:

- **Data exchange platforms** such as Dawex in France, for example.
- **Data space connectors promoted by IDSA Connector report** such as EDC, which is a DSP implementation)[75].
- **Generic technical solutions** such as the SSH File Transfer Protocol (SFTP) or API platforms.
- **SIMPL building blocks.**
- The box with dotted lines indicates a **priority effort to develop** certain types of solutions that are still lacking or immature.

[73] Gaia-X provides a Trust Framework to verify IDs and claims from participants and data offerings, and specifications for trusted data exchanges, covering policy, organisational and legal issues. For more, see: https://docs.gaia-x.eu/technical-committee/architecture-document/25.05/trust_framework_architecture/

[74] https://eclipse-dataspace-protocol-base.github.io/DataspaceProtocol/2025-1/ (previously IDSA Data Space Protocol before v.2025-1)

[75] "The Dataspace Protocol Technology Compatibility Kit (DSP TCK) is the official test suite that verifies whether a connector correctly implements the DSP, serving as a benchmark for interoperability." from https://internationaldataspaces.org/idsa-data-space-connector-report/

5.2.1 An analysis of the SIMPL maturity level and current issues

The SIMPL-Open team had developed a Minimum Viable Product (MVP) with essential features and presented it in January of 2025. Since then, they are working and iterating along the published roadmap[76]. While its architecture is promising, it is still in an early development phase and lacks production-ready features. The V1.1 was released in October of 2025[77].

One may however note the following observations:

- **Limited maturity and stability**: The majority of SIMPL-Open's components, including the federated catalog, governance registry, and data contract enforcement modules, are still in a beta phase.
- **Repository Availability**: the available SIMPL components are here: https://code.europa.eu/simpl/simpl-open/development/agents, they do not all have the same maturity level.
- **ID management:** SIMPL uses x509 certificates and is not expected to support Self-Sovereign Identities (SSI) before 2026.
- **DevOps overhead**: SIMPL-Open requires to run OS software in a Kubernetes-based environment with additional components like ArgoCD, HashiCorp Vault, Helm charts, and Cert-Manager. These dependencies introduce an entry barrier for partners who lack advanced infrastructure and continuous delivery pipelines.

5.2.2 An analysis of the EU LDT Toolbox maturity level and current issues

The LDT Toolbox is still under active development at the time of this Technical Landscape Report. Consequently, a hands-on evaluation of final deployments is out of scope for this report. Readers should monitor forthcoming Toolbox releases and documentation for updates and test results.

Despite this, many tools build on well-established, production-proven technologies, which materially reduces risk, such as:

- Identity Management: Keycloak with PostgreSQL as the core stack.
- Data Platform: Trino (query engine), TimescaleDB (time-series on PostgreSQL), Scorpio NGSI-LD (context broker), FIWARE IDAS (IoT agents), and PostgreSQL.
- City Innovation Planner (visualisation/storage): Plotly.js/D3.js with PostgreSQL.

The following open points summarise key questions and validations still required to reach an operational baseline for the LDT Toolbox.

- Final component selections and Proof-of-Concepts.

[76] See https://simpl-programme.ec.europa.eu/group/simpl-forum-0/discussion/simpl-open-development-roadmap-2025-2026

[77] See https://code.europa.eu/simpl/simpl-open/architecture/-/blob/463b44e6a1f62d8f53aded0a26df066a7e39e987/functional_and_technical_architecture_specifications/Functional-and-Technical-Architecture-Specifications.md

- Interoperability and governance (asset specification alignment across tools and with the Marketplace/Data Space Ready).
- Performance, resilience, and failover targets (SLOs) to be validated under expected loads.
- Evolution of data-space standards and connectors, which may influence integration choices.

5.3 Interoperability in practice

This section translates the theoretical interoperability EIF layers into actionable steps, illustrating how legal, organizational, semantic, and technical interoperability can be achieved in real-world projects. It includes examples and best practices for designing interoperable data flows, agreements, and system integrations.

Here's a **practitioner-focused version of LOST layers**:

Legal interoperability (L) : "Are we allowed to share this data?"

- Check legal basis, the General Data Protection Regulation (GDPR) (purpose, minimisation), retention periods etc.
- Put in place **data-sharing agreements** (municipality, inter-municipal body, region, state, vendors).
- Example: *if someone wanted to be able to send citizens' addresses to the waste contractors, they would have to put it in writing in the contract and check GDPR clauses.*

Organisational interoperability (O): "Who does what, when, with what commitment?"

- Define the **end-to-end process**, roles (data owner/producer/consumer), and a Service-Level Agreement, or **SLA** (refresh rate, delays, availability, latency, throughput, maintenance windows, data retention, data quality, incident response times, audit and logging, security and compliance, versioning).
- Document contacts and escalation.
- *Example: Civil registry records are fed to the school system every night. In the case of an incident, the IT service is charged with managing the latter.*

Semantic interoperability (S): "Do we mean the same thing?"

- Align **meaning** of fields: same territorial code, same controlled vocabularies, same units and time references.
- Provide a **data dictionary** and mapping tables between types (entities and properties) and ontology's Internationalised Resource Identifier (IRI)s.
- *Example: In France, each subterritory, or "commune", is identifiable via a 5-digit INSEE (French organisation) the first two digits correspond to the department and the next three digits correspond to the "number" of the municipality. (In Europe, administrative entities are aligned with the NUTS standard).*

Technical interoperability (T): "How do we connect and secure it?"

- Choose exchange method (API, SFTP, event bus), **formats** (Comma-Separated Values (CSV)/JSON/GeoJSON/JSON-LD), **security** (Hypertext Transfer Protocol Secure (HTTPS), OAuth2, keys) etc.
- Plan **versioning**, integration tests, monitoring, and logs.
- *Example: One may interconnect via the use of JSON/HTTPS API with OpenAPI docs, per-partner token, logging and metrics for technical interoperability.*

  Json-LD provides greater interoperability.

Full example: Urban-Flood Digital Twin (local authority) –LOST explained

- **Technical interoperability (T)**
  Some defined sensor data flows in real-time through an event bus[78] into the NGSI-LD context broker, then into the 2D hydraulic model and API services. Secure channels (HTTPS, OAuth2/Keycloak), versioning, logging and monitoring guarantee that the whole digital chain works reliably end-to-end.

- **Semantic interoperability (S)**
  Measurements and alerts are expressed with common terms and references: *waterLevel* in metres, *flowRate* in m^3/s, *alertStatus* in {pre-alert, alert, crisis}, all timestamps in ISO 8601 UTC[79], all locations in WGS84 (*World Geodetic System 1984*), all territories/local authorities by territorial code (like INSEE Code in France). This shared dictionary ensures everyone interprets the numbers and alerts in exactly the same way.

- **Organisational interoperability (O)**
  Each actor has a clear role: the hydraulics department owns the model, IT one ensures the platform runs, and the crisis unit decides on alerts. Service agreements set the rhythm: sensors update every minute, maps every ten minutes, with documented on-call and escalation procedures when something goes wrong.

- **Legal interoperability (L)**
  The whole setup operates within a legal framework: GDPR rules are respected (addresses are pseudonymised), licences and retention periods are defined, and data-sharing agreements link cities, intermunicipal authorities, counties, and/or utilities. This legal basis makes the exchange legitimate and enforceable.

5.3.1 Technical interoperability in practice

This level is well covered thanks to the technical standardisations done in recent decades. These standards enable data to be exchanged using well-established and widely shared protocols. In addition, new components and protocols, designed specifically for data spaces, are emerging.

[78] An event bus facilitates real-time communication about event data between event publishers and event subscribers.
[79] See https://www.iso.org/fr/iso-8601-date-and-time-format.html

One should use open, widely adopted standards, specifications and vendor-neutral interfaces to connect heterogeneous systems, in line with EIF principles (openness, reusability, interoperability-by-design), and prefer formal, or *de facto,* open standards from recognised bodies and profile them for public-sector use such as the ones described in this Technical Landscape Report for Pilots (see 5. Technical solutions enabling interoperability).

Given that data spaces and LDTs are disjointed and composed of participants with widely varying technical capabilities and approaches, it is essential for interoperability to ensure the existence of an intermediate technical-functional layer that provides the technical “link” between the technical standard adopted by the applications used by the data provider and those used by the data acquirer. For example, a data provider may want to expose its data via an API, while the purchaser may want to receive it as a file.

In this context, an interoperability strategy by the governance authority should favor solutions that are agnostic at the technical level, capable of enabling communication between participants with heterogeneous technical infrastructures.

5.3.2 Syntactic and semantic interoperability in practice

A. Syntactic interoperability

This layer is already supported by numerous well-established data standards, even though new ones regularly emerge as applications evolve.

Widely used structured formats include:

- **Text formats** (XML, JSON, CSV etc.)
- **Multimedia containers** (image, audio, video etc.)
- **Office document formats** (OpenOffice etc.)
- **Geospatial standards** (OGC etc.)
- **Sector-specific formats** (ontologies of domains for construction, mobility, health, decarbonisation, etc.)

The main challenge lies in enabling automatic communication between participants and applications that rely on different syntactic formats.

An effective interoperability strategy must therefore either **mandate common syntactic formats for each sector by use case across all territories/local authorities**, or **provide an intermediate technical-functional layer** –such as an API gateway or conversion service- that can automatically transform data from one format to another.

Also, it is recommended to adopt syntactic formats that provide support for semantic descriptions such as JSON-LD, CSVW (CSV on the Web), etc., since these facilitate unambiguous format transformations and further support the materialization of Semantic interoperability. Minimal Interoperability Mechanisms for syntactic operability are described in MIM Plus 0 on Data Access and MIM Plus 2 on Data Representation.

B. Semantic interoperability

Equally important is a shared understanding of the meaning of data. **Sector-wide semantic standardisation** greatly reduces the need to reprocess or reinterpret exchanged information. As such, if one were to simulate a certain phenomena, i.e. were to predict or have an answer to a concrete problem, semantic interoperability would be useful because using data from cross-domain sectors would usually be a must in order to process them all (in Extract – Transform – Load process).

While many domains (e.g., healthcare or environmental initiatives) are actively developing semantic standards, significant work remains to ensure that all stakeholders can rely on clear and common vocabularies, models, and reference codes.

In the absence of shared standards, organisations may establish **local agreements**, rely on **data engineering teams** to adapt incoming datasets, or, in the long-term, explore **automatic "translations" with specialised generative AI**.

A robust interoperability strategy should therefore pursue a **dual approach**:

1. **Promote the emergence of sector-specific syntactic and semantic standards** at the European level, detailed enough to cover real use-cases in each sector or profession.

2. **Encourage functional solutions** that can automatically map or transform both syntactic and semantic standards, so that applications communicate seamlessly within and across territorial data spaces and local digital twins.

Minimal Interoperability Mechanisms for semantic operability are described in MIM Plus 2 on Interlinking Data and MIM Plus 3 on Exchanging Data.

5.3.3 Organisational interoperability

A. Political

To enable interoperability among community data spaces with diverse legal forms and governance structures, it is essential to **establish shared rules for collective operation.** These rules concern the business model (between community data spaces or platforms), governance, decision-making and escalation processes, and the organisation that will oversee this governance.

Thus, any interoperability strategy within and between community data spaces will need to design clear governance processes at the "local" and "federal" levels and consider the creation of a governance organisation in a constructive dialogue with the national authority of regulation.

More specifically, the interoperability of business models will need to be worked on further in-depth. For example, if access to a community data platform A were subject to subscription conditions and fees for the use of services, it would be necessary to determine under what conditions other platforms, and their users, could access the products and services of said platform A.

B. Organisational

Trust between stakeholders, as well as **respect for confidentiality and data security**, are **prerequisites** for any data exchange, whether within or between community data spaces. To ensure these conditions are met, a number of elements are necessary:

- Ensure that the **organisations**, individuals, or even applications participating (as data providers or acquirers) **are who they say they are**. This involves **identity verification and verifying claims** (See *4.4. Gaia-X* for more info).
- Define and **manage data access rights based on the identities and roles** defined for **each participant**. This requires a "common" access rights' management system, which necessitates the presence of federated services among territorial data platforms.

Furthermore, the fact that the various community data platforms are interoperable means that **catalogs of data products and services exist at two levels**:

1. Within a territorial platform (**locally**),
2. Federated between all territorial platforms (**regionally or nationally**).

This implies that the **various "local" catalogs can interoperate with "national" catalogs**. To achieve this, the following conditions must be met:

- **Structure of descriptive metadata** for products and services that are common or compatible with each other (see *Semantic interoperability*);
- **Shared** or compatible **taxonomies** (see *Semantic interoperability*)**;**
- **Structure of contractual and commercial metadata** that is shared or compatible with each other (see *Legal interoperability*)

These issues must be **addressed at the governance** *(policy)* **level** in order to define common standards, but also **at the level of underlying technologies** (data exchange solutions sharing the same principles for metadata structure).

It should be noted that this technical level of interoperability between catalogs is highly dependent on the level of legal interoperability, as access rights will be determined in particular by the contractual conditions defined when it comes to the access to each dataset or application. For example, open data will not require access rights' control, while private commercial data will only be accessible after a contract has been formally concluded between the provider and the purchaser of the data. But it should also be noted that this technical level of interoperability among catalogs is strongly dependent on legal interoperability, which determines access rights, since contractual conditions define whether data are open (no access control) or private/commercial (access only after a formal contract).

There are **international initiatives aimed at standardizing** this level. The most advanced, and the **only one that takes into account industrial needs** and notions of **sovereignty**[80], is **Gaia-X** (see 4.4. Gaia-X).

[80] The Gaia-X Compliance Document, which defines compliance as well as labels, introduces specific criteria in terms of contracting, cybersecurity, data protection, sustainability, portability and (European) sovereignty. It is based on industrial and regulatory criteria. See: https://docs.gaia-x.eu/policy-rules-committee/compliance-document/25.03/

5.3.4 Legal

Practically-speaking, legal interoperability should be ensured at different levels, to facilitate the circulation of data, i.e.:

- Between data spaces/data platforms, and LDTs;
- Between organisations;
- Between uses-cases.

NB: It is good practice.

This involves defining the terms and conditions of use (TCUs) that apply to all. This is an important element in building trust and laying the foundations for the interoperability of governance described above. To this end, local authorities can rely on various national and European regulations[81]. The Data Governance Act[82], which came into force in September 2023, defines the obligations and responsibilities of organisations that offer data exchange services (known as Data Intermediation Service Providers, or DISPs). This regulation will be monitored in each country by an authority of regulation designed by each state.

Table 2 provides a summary of the paragraphs above for quick reference.

EIF Levels	Components (to put in place)	Expected outcomes
Governance	Selection of Frameworks, decisions and roles for interoperability and lifecycle of standards and building blocks reuse policies monitoring/evaluation (e.g., CAMSS). Design and end-to-end orchestration of services portfolio and reuse management lifecycle management, change management, continuous improvement. Legal bases, GDPR/eIDAS, clauses and contracts/licences for data sharing impact assessments.	Coherent, traceable decisions; participants aligned on shared standards and principles. Integrated, reusable services with sustained continuity and quality.
Legal	Cross-border regulatory alignment.	Data shareable in compliance, with clear rights and restrictions.
Organisational	Roles and responsibilities, shared processes, operational agreements (Memorandum of Understanding (MoU)/Operational Level Agreement (OLA)), SLAs, escalation and support procedures.	Predictable cooperation between organisations; committed service levels and quality.

[81] See https://digital-strategy.ec.europa.eu/en/policies/strategy-data
[82] See https://digital-strategy.ec.europa.eu/en/policies/data-governance-act-explained

Semantic (incl. syntax)	Data models, vocabularies / ontologies, code lists, metadata schemas (JSON Schema/XSD), URI conventions, master data registers validation rules.	Machine-interpretable, unambiguous data with shared meaning and structures.
Technical	Open interfaces & protocols (HTTP(S), OGC API, eDelivery/AS4, MQTT/AMQP SFTP as fallback) APIs (REST/OData) and descriptions (OpenAPI) security (Transport Layer Security (TLS), OAuth2/OIDC), logging, testing, versioning.	Interoperable and secure systems, reliable exchanges via vendor-neutral interfaces.

Table 17. Components to put in place to align with the EIF

Non-Technical resources will be shared by the LDTT4SSC consortium, to assist pilots in incorporating legal clauses at all stages of a use case implementation.

6. Interconnection of LDTs (WS1)

This chapter explains the rationale and methods for interconnecting LDTs, either through a data space or between themselves without a data space, in order to create a cohesive, trustworthy, and real-time data ecosystem. It discusses the role of data space connectors, identity federation, catalog sharing, and contractual management in enabling seamless cross-platform interoperability.

The first Work Strand (WS1) of the LDT4SSC project aims at connecting data platforms and LDTs from cities and communities that already have an LDT in place, to create an EU "federation" of LDTs. Reinforced interoperability through the aggregation of LDTs at a larger scale (cross sectors, cross cities, and cross borders) will help to scale up the EU common data sets and open-source solutions. It will also facilitate less advanced cities and communities joining the existing EU LDT ecosystem.

The different data platforms that can be interconnected among each other are:

- A data space interconnected with another data space, both connecting data platforms locally and creating their own respective LDTs;
- A LDT interconnected with another LDT;
- LDTs interconnected with a data space in which the latter would also have an LDT.

6.1 Why interconnect a data space and a context broker?

More broadly, while addressing distinct but complementary challenges, data spaces and LDTs, when combined, lay the foundations for a reliable, interoperable, and real-time data ecosystem.

This subsection articulates the complementary nature of data spaces and digital twins, showing how their integration enhances data governance, contractual management, and real-time contextualization, ultimately accelerating innovation and collaboration.

6.1.1 Data Space connectors

For a local authority leading an interoperability project, **data space connectors, as defined in the Data Space Protocol**[83]**,** are the key enablers of trust and seamless data exchange within data spaces. At the heart of this approach lies **data sovereignty**, ensuring that one's administration and partners remain in control of the data they share, while operating on a level-playing field with other territories, businesses, and citizens.

However, new data spaces may adopt different technical implementations or standards, creating the risk of **new silos**. To avoid this, there must be a strong push for **convergence**: aligning standards, guaranteeing continuity of data flows, and adopting shared governance models that secure interoperability and uphold data sovereignty across all data spaces.

As a reference, the **IDSA Rulebook**[84] provides an overview of the essential functions of a data space, its core architecture, and the distinction between mandatory and optional capabilities. This guidance can help local projects align with European and global practices.

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[83] https://internationaldataspaces.org/offers/dataspace-protocol/
[84] See https://internationaldataspaces.org/idsa-rulebook/

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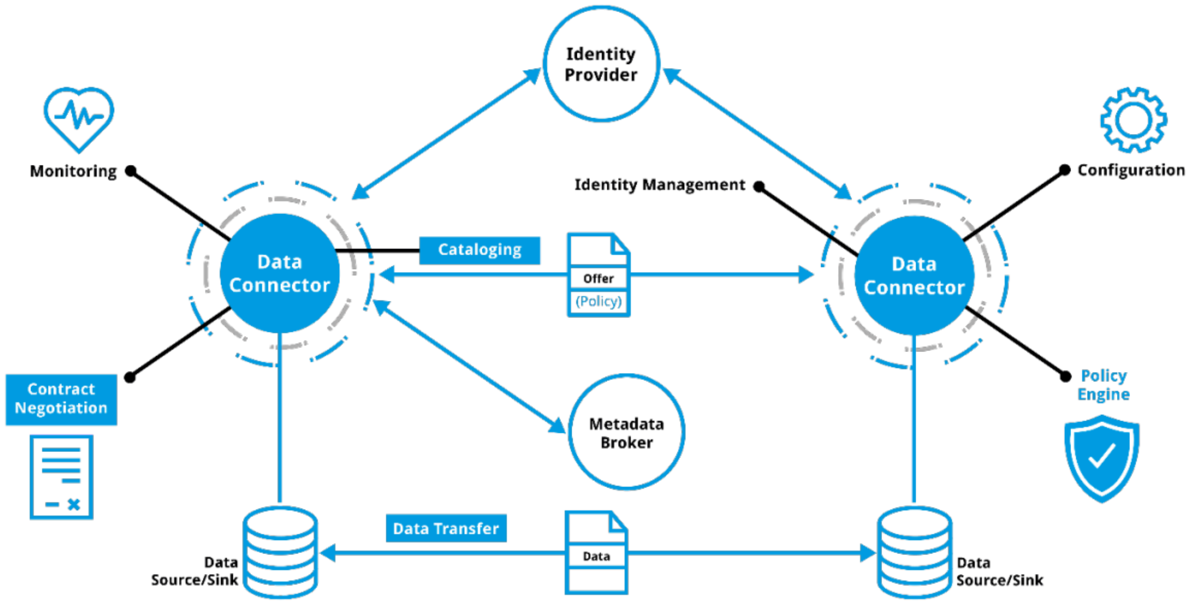

Figure 16. Data Exchange Services realised by a data connector (source: IDSA[85])

In this Rulebook, Figure 16 is presented as it depicts the interaction of the connectors on a more general level. At the bottom is what is called the **Data Plane** (Data Source/Link, Data, Data Transfer), which offers several possibilities for different data sharing scenarios: the confidential data sharing, the streaming of data, along with event-based data, edge devices, etc. Conversely, Data (space) connectors, Policy Offer and Cataloging as well as Identity management constitute the **Control Plane**, which offers one standard procedure to negotiate data sharing. These connectors require a protocol-agnostic standard as a foundation for interoperable data spaces.

As a result, IDSA worked on a specific Dataspace Protocol (DSP), i.e. a set of specifications designed to facilitate interoperable data sharing among entities governed by usage control and based on web technologies. IDSA released v0.8 & 2024-1. Current release (2025-1) and subsequent releases are now under Eclipse Dataspace Protocol project, associated with the Eclipse Dataspace Working Group, under the governance of the Eclipse Foundation (EF)[86]. These specifications define the schemas and protocols required for entities to publish data, negotiate usage agreements, and access data as part of a federation of technical systems termed a data space. The Dataspace Protocol therefore represents the foundation for technical interoperability in data spaces. Following this Rulebook means that every data connector used in a data space must implement the DSP.

6.2 How Do Data Spaces and Data Platforms Interconnect?

At the regional or national level, the relationship between **data spaces** and **data platforms** can be visualised as follows, with an **interoperability framework** facilitating their connection.

There are three elements to focus on in this Figure 17:

85 https://internationaldataspaces.org/wp-content/uploads/dlm_uploads/IDSA-Data-Connector-Report-84-No-16-September-2024-4.pdf

86 See https://github.com/eclipse-dataspace-protocol-base/DataspaceProtocol?tab=readme-ov-file

1. **At the top is the Data available** in a given Community A. As often in territories/local authorities, data is siloed, i.e. the organisation of data within said Territory/Local Authority A is modelled on the siloed organisation of public organisations.
2. **At the bottom** are the **different data platforms** usually set up in different communities.
3. In the **center** is the **data-exchange solution**. The latter needs to be well-orchestrated for data to be seamlessly exchanged from a provider in its silo to a platform, in between platforms and in between silos. The interoperability is based firstly on the use of standard data models, and then on the technical data-exchange solutions.

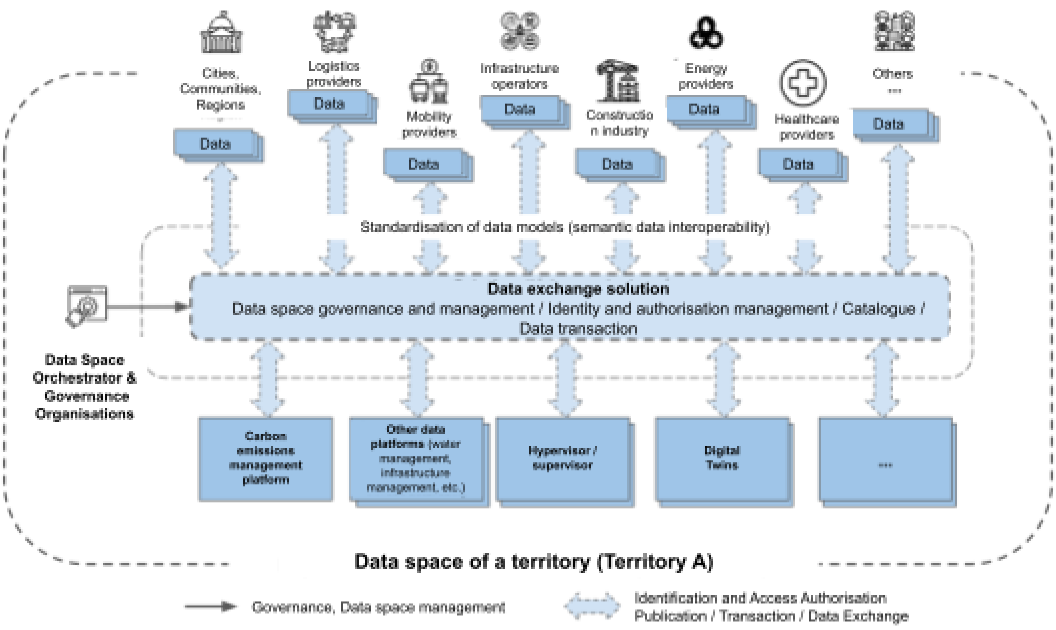

Figure 17. Illustration of a territory's/local authority's data ecosystem

What is important to notice with these two Figures (17 and 18) is that interoperability operates on two levels:

- Between the siloed data within a local authority (Figure 17)
- And between local authorities (Figure 18) as most of the time, they have the same data organisation.

To illustrate Figure 18 with a concrete scenario: one can imagine two frontier communities facing a common challenge (e.g. traffic management of commuters, waste management, etc.). These communities need to share data to address and overcome the common challenge despite having an administrative border. They have to interconnect the data exchange solutions in an interoperable way to do so.

Technical & Syntactic Interoperability is made possible through the data exchange solutions. While **semantic and Governance Interoperability** is enabled through governance organisations, relayed by data space operators, supported by data exchange solutions and monitored by connected application platforms.

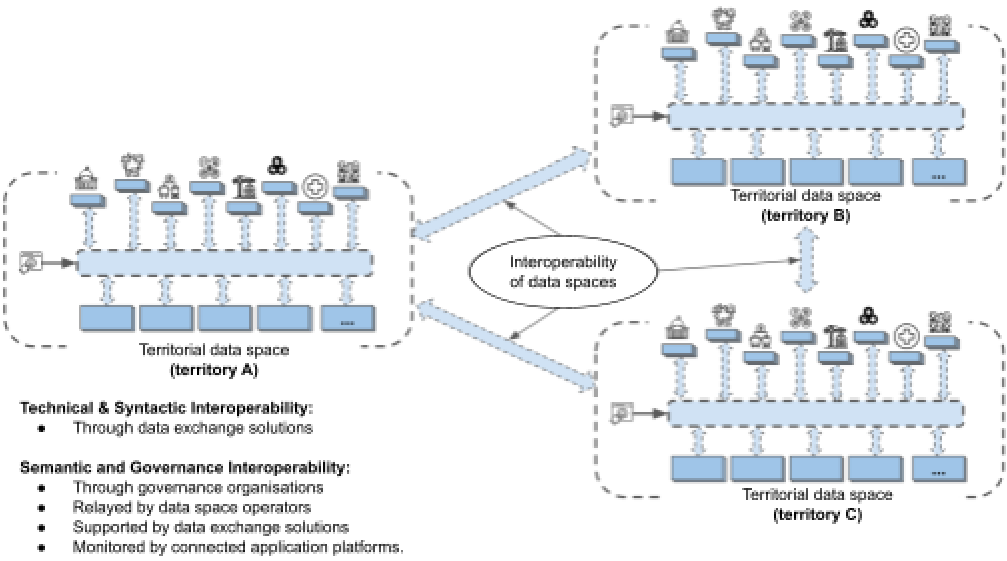

Figure 18. Schematic representation of data space interconnection

6.2.2 Resources to interconnection

In this section are described the resources that make up a data space and how they enable interconnection.

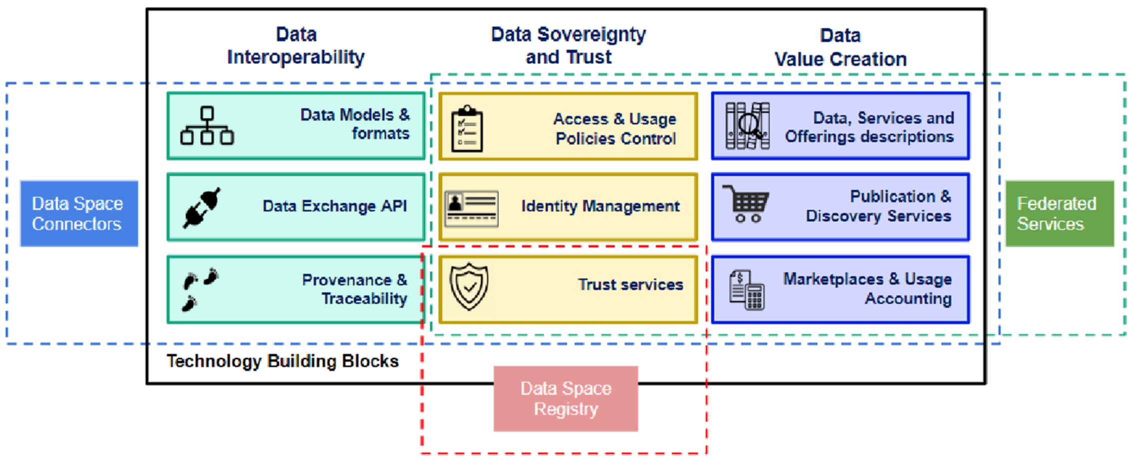

Figure 19. Data Space architecture and technical building blocks (source: FIWARE[87])

Figure 19 shows how **autonomous participants** share data **without a central warehouse**, using **connectors** and **federated services**. To go further:

- In the **middle column "Data Sovereignty & Trust"** and boxed as "Data Space Registry", Trust Services provide the **trust anchors** (who is who, who may access what, under which conditions).
- The **two rightmost columns, i.e. "Data Sovereignty & Trust" and "Data Value Creation"** (boxed as "Federated Services"), provide **shared ecosystem services** (catalog, contracting, compliance, monitoring).

[87] See https://github.com/i4Trust/building-blocks/blob/main/README.md

- The box containing **“Data Space Connectors”** surrounds all 3 categories/columns because **all flows go through connectors** on both the providers’ and the consumers’ sides.

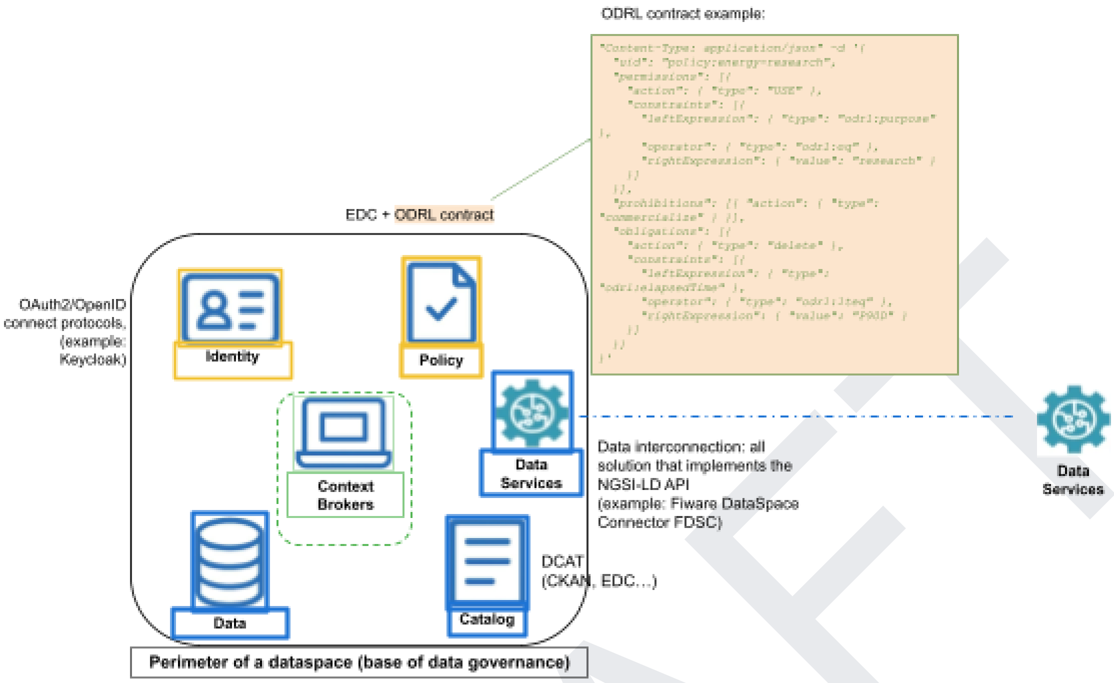

Figure 20. Resources to interconnection

Figure 20 presents the data space resources needed for interconnection. As shown in this figure, when trying to link LDTs to an existing data space, the following components should be set up:

1. A data catalog (DCAT);
2. A data management system that can manage any type of data such as: JSON-LD, RDF, NGSI-LD;
3. An identity management out of the following: OAuth2, OpenID connect, keycloak;
4. A data policy out of the following: EDC + ODRL contract;
5. A data connector from this list: Data Space Connector Report[88].

NB: The colors used in Figure 20 are coherent with the ones in Figure 21 below presenting the overall data space architecture. In **blue** is the Data Value Creation, in **yellow** the Data Sovereignty & Trust and in **green** are the components for Data Interoperability.

6.2.3 Interconnection of Local Digital Twins

Figure 21 presents a summary of what should and what could be present in either a data space or an LDT in order to interconnect them together –particularly in the context of the Work Strand 1 of LDT4SSC: interconnecting LDTs, but also in the context of the other Work Strands of the LDT4SSC project.

[88] See more: https://internationaldataspaces.org/publications/most-important-documents/

Funded by the European Union

NB 1: What we call “perimeter” here simply refers to the scope of what is needed / preferential to have in the context of either data spaces or LDTs for their interconnection to be possible.

NB 2: The colors used in Figure 21 are coherent with the ones in Figure 20 above presenting the resources to interconnection. In **blue** is the Data Value Creation, in **yellow** the Data Sovereignty & Trust and in **green** are the components for Data Interoperability.

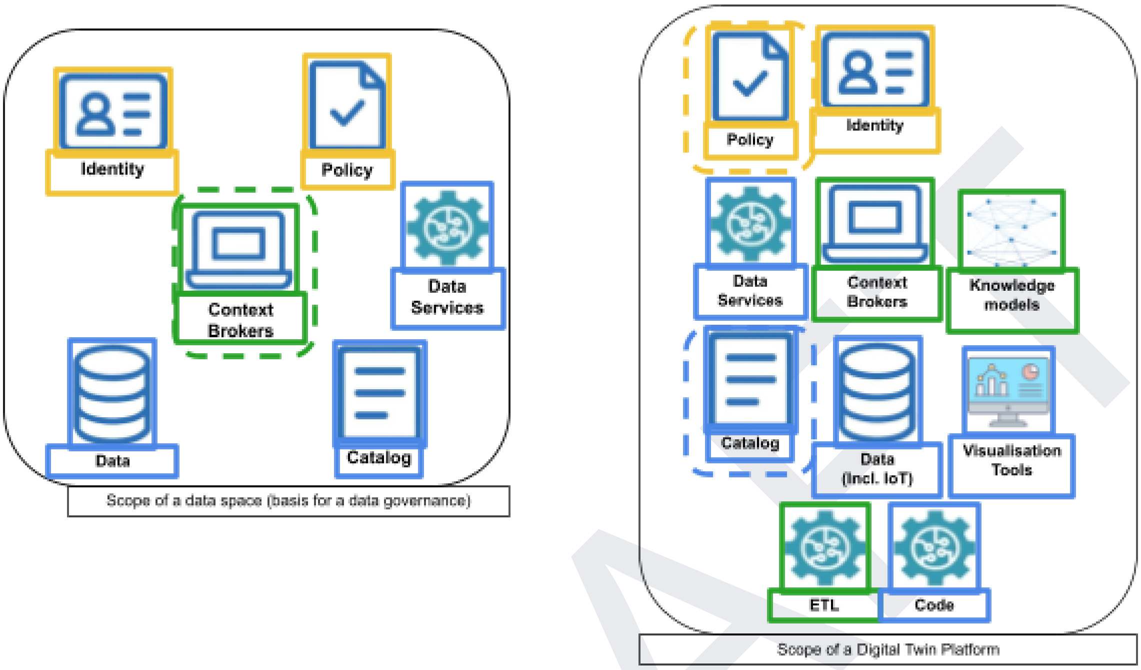

Figure 21. Functional scope of a Data Space vs. of a Digital Twin

On the one hand, the perimeter/scope of a Digital Twin, as shown on the right-hand side of Figure 21 in the red contour, describes the several components that are usually found in LDTs. To be more precise, we should highlight that:

- The **core of a Digital Twin is based on a context broker and a knowledge meta-model**, the latter which links the multiple business knowledge models that the Digital Twin manages.
- The **other software components are additional**, and they enable:
  - Integration of data (ETL),
  - Management of access rights to the digital twin's data and services (Identity),
  - Production of visualisations,
  - etc.

Digital Twins are further fed with data from the context broker and, with a Business Intelligence (BI) overlay, which allows for tangible for the end-user data analysis.

The components of the perimeter of an LDT that are circled with dotted lines (Policy and Catalog) are not essential *per se* to the Digital Twin but enable the interconnection with other Digital Twins:

- Policy describes the obligations and rights of both the data producer and the user; the former describes how a user can use the data at hand, and the latter says what they want to do with the data. A verification is then carried out using Open Digital Rights

Language (ODRLs) managed by the Eclipse Data Component (EDC), SIMPL is in charge of enabling this.

- Catalog: Having a solution that enables the data cataloguing of one's data (exposing the datas' metadata) as well as the consumption of data from other data catalogues for interconnection.

On the other hand, the perimeter/scope of what is needed in data spaces for them to interconnect with LDTs, as shown on the left-hand side of Figure 21, covers all aspects of contractual data management. That is to say, data spaces which want to be interconnected with LDTs must have a control of Identity (using Verifiable Credentials), specific Policies in place, Data and Data Services, along with Catalogs. The green dotted lines indicate that the integration of a context broker is not mandatory, but when data spaces want to interconnect with digital twins, it is desirable.

Considering all of the above, we would tend to recommend:

- **the integration of data space software components into Digital Twins in order to interconnect the LDTs directly with each other** (As shown on the right hand side of Figure 21 depicting the functional perimeter of digital twin), **or;**
- **the interconnection of the LDTs via a data space. In this case, the digital twins must use a data space connector.**

The **FIWARE Data Space Connector** is an integrated suite of components that any organisation participating in a data space should deploy in order to connect to the latter. In line with the recommendations of the **Data Spaces Business Alliance (DSBA)** (data-spaces-business-alliance.eu), it enables the following features:

- **Integration with trust services** compliant with **EBSI (European Blockchain Services Infrastructure)**[89] specifications.
- **W3C DID- (Decentralised Identifiers) based authentication** using **VC/VP standards** and **SIOPv2**[90]**/OIDC4VP**[91] **protocols**.
- **Attribute-Based Access Control (ABAC)**[92] **authorisation** following a **XACML P*P architecture**, using **ODRL (Open Digital Rights Language)**[93] and the **OPA (Open Policy Agent)**[94].
- **Compatibility with the ETSI NGSI-LD data exchange API**.
- **Support for TMForum APIs**[95] for contract negotiation.

Note: While the FIWARE Data Space Connector is compatible with the **NGSI-LD data exchange API**, it can also be used with any other **RESTful API** by replacing or extending the connector's **PDP (Policy Decision Point)** component.

[89] See https://digital-strategy.ec.europa.eu/en/policies/european-blockchain-services-infrastructure
[90] See https://github.com/openid/SIOPv2
[91] See https://openid.net/sg/openid4vc/
[92] See https://nvlpubs.nist.gov/nistpubs/specialpublications/nist.sp.800-162.pdf
[93] See https://www.w3.org/community/odrl/wiki/Main_Page
[94] See https://www.openpolicyagent.org/
[95] See https://www.tmforum.org/oda/open-apis/directory

Furthermore, the features listed above allow an organisation to connect to the data space as a **data processing service provider**, a **data processing service consumer**, or both.

Technically, the **FIWARE Data Space Connector** is a **Helm Umbrella Chart**, containing all sub-charts and their dependencies for deployment via **Helm**. As such, provided as a **Helm Chart**, the FIWARE Data Space Connector can be deployed in a **Kubernetes environment**.

Source: *FIWARE Data Space Connector on GitHub*

A data space does not necessarily have a context broker. A context-broker is a good solution to manage semantic interoperability. A dataspace is a good solution to manage the contractual interoperability.

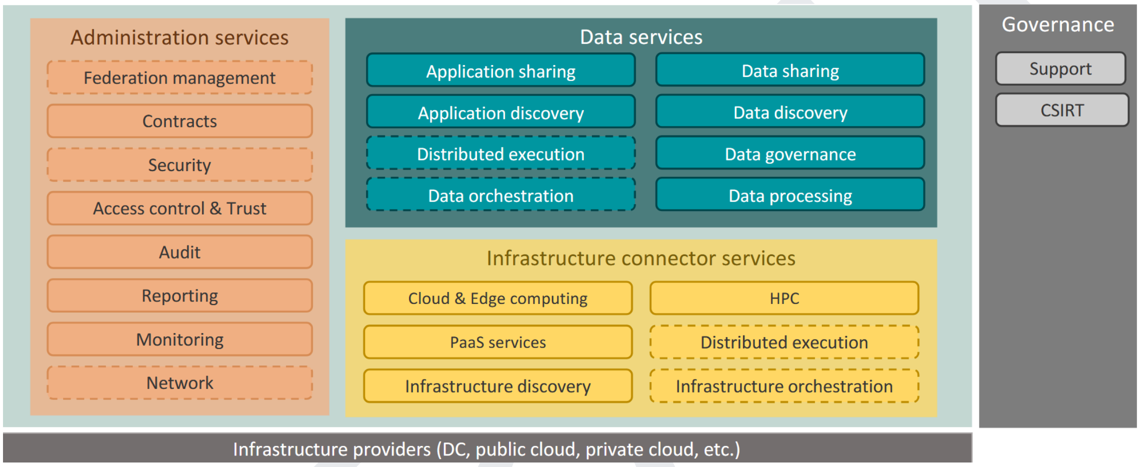

Figure 22. SIMPL conceptual Architecture (source: SIMPL)[96]

As highlighted in Figure 22, in order to interconnect context brokers, it is necessary to manage the following, upstream:

- Legal right to use the API of another context broker;
- Have a token for a successful authentication;
- Federation of identities;
- Beforehand: share data catalogs and have a setting up of EDC to access data.

LDT initiatives should note that the following two issues need active work with respect to current interconnection tools such as SIMPL.

- For the interconnection of context brokers, the API key is not sufficient. Indeed it authenticates the context, but more is needed (in connection with MIM6[97] – Securing data).

[96] https://www.data-spaces-symposium.eu/wp-content/uploads/2024/04/13.55-Manuel-Mateo-Goyet-SIMPL_EC-Slides_DSSCSymposium24_Final.pdf

[97] https://app.gitbook.com/o/-MUhlh2R8PEe8auBp_S-/s/ASI4EOhjMRmhAqlLxwCO/mim6-securing-data

- In theory, the generic nature of NGSI-LD APIs allows for the interconnection of context brokers, but it will certainly be necessary to document MIM1 –Interlinking Data, more thoroughly, as this documentation is currently lacking. For instance with information on the interoperability of the API structure.

6.3 Why contextualise Data ?

Contextualising data is essential for creating digital twins. It is the very heart of a digital twin. The more contextualised the data, the easier it will be to establish links between data and cross-functional analyses.

Context brokers simply map out data to multiple knowledge models. It is therefore necessary to follow the FAIR (Findable, Accessible, Interoperable, Reusable) principles:

FAIR Principle	Link to ontology reuse
Findable	Reusing well-known ontologies (Data Catalog Vocabulary (DCAT), Semantic Sensor Network Ontology (SOSA), Smart Appliances REFerence (SAREF)...) provides standardised, documented identifiers, making concepts easy to discover.
Accessible	Standard ontologies are usually open, with persistent access points (URIs, SPARQL endpoints) ensuring accessibility.
Interoperable	Shared vocabularies ensure that different systems interpret concepts consistently (same semantics, same syntax).
Reusable	Published concepts with clear licenses can be integrated directly, avoiding duplication and staying aligned with the community.

Table 3. Overview of the FAIR principle

Methodology:

1. Reuse existing models where they exist, or;
2. When a standard in the business line exists but has not yet been modelled in the form of a knowledge model (understandable by a machine), use it and model it, or;
3. Rely on business publications to build the knowledge model; concepts must be defined at least in the form of URIs, but when working on a European or international scale, IRIs should ideally be used;
4. Then, publish the ontology, if it has not already been published.

CAMSS[98] is the European guide for assessing and selecting standards and specifications for an eGovernment project, a reference when building an architecture and an enabler for

98 https://joinup.ec.europa.eu/collection/common-assessment-method-standards-and-specifications-camss/glossary/term/camss

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justifying the choice of standards and specifications in terms of interoperability[99] needs and requirements. It is fully aligned with the European Standardisation Regulation 1025/2012.

In all cases, follow the Common Assessment Method for Standards and Specifications (CAMSS) guide: CAMSS | Interoperable Europe Portal

To conclude this part, we could say that the ultimate challenge when it comes to contextualisation of data is to govern knowledge models. This has not yet been achieved. Smart data models are an interesting resource that prevents us from having to start from scratch, but everyone modifies or adds to smart data models without any collective governance.

Moreover, **Artificial Intelligence (AI)** will also benefit from the shift in data modeling practices towards **knowledge** modeling, which is richer and more efficient for training AI on targeted knowledge models (especially when AI is used in specialised ways). AI is both a consumer and a producer of data. It will be less costly and more effective when working with structured data.

Knowledge models are also essential for understanding how AI operates. It is therefore necessary to facilitate access to **structured, context-specific data** tailored to specific professions or use cases. Additionally, territories/local authorities must develop a **"meta-data model"** to which these contextualised, profession-specific data models –known as **knowledge models–**- can be linked.

To delve deeper into knowledge models:

To enhance interoperability, creating a **knowledge model** (or **domain ontology**) helps structure, connect, and share data in a consistent and reusable way. Here are key resources to explore:

W3C Semantic Web Standards: Semantic Web technologies (W3C standards) provide proven frameworks for structuring and linking knowledge:

1. **RDF (Resource Description Framework):** Represents subject-predicate-object triples.
2. **OWL (Web Ontology Language):** Enables expressive ontologies (hierarchies, constraints, etc.).
3. **SKOS (Simple Knowledge Organisation System):** Useful for thesauri or controlled vocabularies.
4. Learn more: http://w3.org/standards/semanticweb

Interoperability Solutions for European Public Administrations (ISA): The EU offers practical resources for modeling knowledge with cross-border interoperability in mind:

5. **Core Vocabularies** (person, location, public service, etc.)

99 https://joinup.ec.europa.eu/collection/common-assessment-method-standards-and-specifications-camss/glossary/term/interoperability

6. **Core Public Service Vocabulary (CPSV):** Useful for modeling public services.
7. Methods for creating and using vocabularies.
8. Learn more: https://interoperable-europe.ec.europa.eu/collection/semic-support-centre/core-vocabularies

More information on contextualising data and semantic interoperability can be found in the documentation of the **MIM Plus 1 Working Group on Interlinking Data**

Example
Île-de-France Public-Transport Knowledge Model: Île-de-France Mobilités (IDFM) built a knowledge model based on open standards (NeTEx, SIRI) to:
- Describe lines, stops, schedules, and disruptions.
- Publish data via interoperable APIs (Open API).
- Enable reuse by operators, mobility apps, researchers, etc.

This model relies on shared ontologies and vocabularies, ensuring a "by design" interoperability with partners like SNCF, RATP, Waze, and CityMapper.
- Open Data: IDFM Open Data
- Documentation: IDFM Reference Guide (PDF)

7. Implementing the pilot in WS1, WS2, WS3

7.1 About the LDT4SSC Work Strands

The LDT4SSC project is composed of three different Work Strands (WS) that aim to effectively help local authorities. The scope of the work strands is outlined as follows:

Work Strand 1 (WS1) focuses on interconnecting existing LDTs to create a federated EU-wide network supporting seamless data exchange and interoperability;

Work Strand 2 (WS2) aims at creating new LDTs based on common urban challenges like mobility, energy, and sustainability to foster replicable solutions;

Work Strand 3 (WS3) develops advanced AI-based tools and innovative open-source components to enhance LDT capabilities with immersive and predictive services.

Together, these strands support scalable, sustainable, and inclusive digital transformation aligned with European policies and market development.

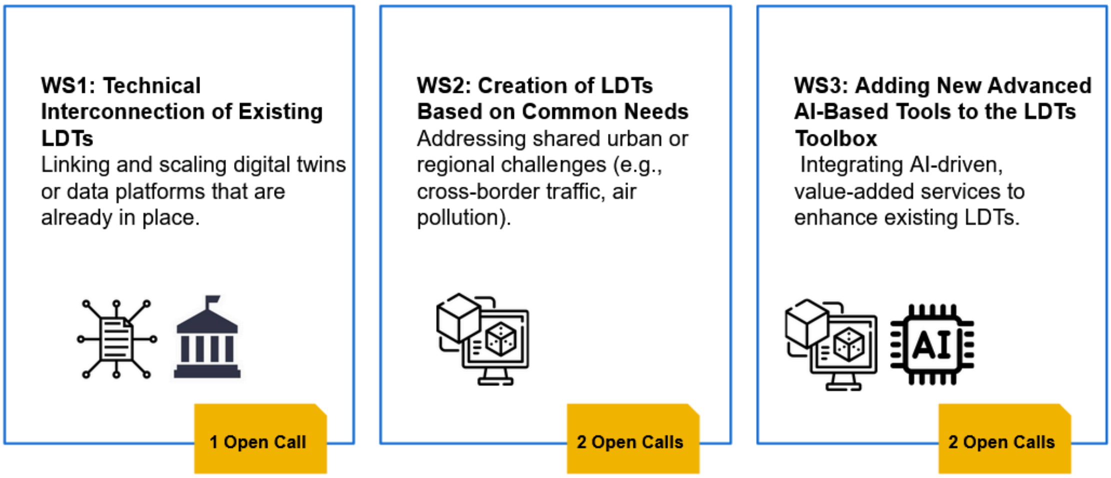

Figure 23. LDT4SSC three Work Strands across five Open Calls

Ready-to-use, documented technical components are available and are described in chapter 5. Technical solutions enabling interoperability.

7.2 Deployment of uses-cases

When communities are in the process of launching an LDT, one should keep in mind that the MIMs Plus are useful at all stages of deploying a business use case, particularly as they help local authorities define what aspects to put attention to when it comes to interoperability (See 2. Interoperability for more).

As part of the technical and non-technical resources provided to prospective pilots, the awarded pilots will receive support to work towards MIMs Plus compliant LDTs and contribute their findings to the respective MIM documentations. Details of the various stages will be provided in a separate document at a later date as part of the Technical resources for pilots.

Figure 24 is the draft version of the overview of this methodology for pilot use-case implementation. It illustrates the emphasis that should be put on which MIM at each stage, within the 4 steps (1) definition of the use case, (2) data access management (3) Integrating flows into an ETL, (4) valorisation/scaling up to deploy a use-case. It presents the steps to create a "Descriptive" LDT (see 3.2.2. Digital Twin).

Two examples will be presented in this resource to illustrate the phases "Data access management" and "Integrating flows into ETL":

1) The first example of a use case implementation will be for monitoring the energy consumption of businesses such as retailers and craftsmen. This example will allow pilots to familiarize themselves with the use of a context broker.
2) Another example of a Digital Twin with "Prediction" capabilities thanks to AI-based simulation services will also be shared. This example aims at helping pilots understand how to integrate AI into the creation of a Digital Twin, in addition to completing all the 4 elementary steps introduced in Figure 24.

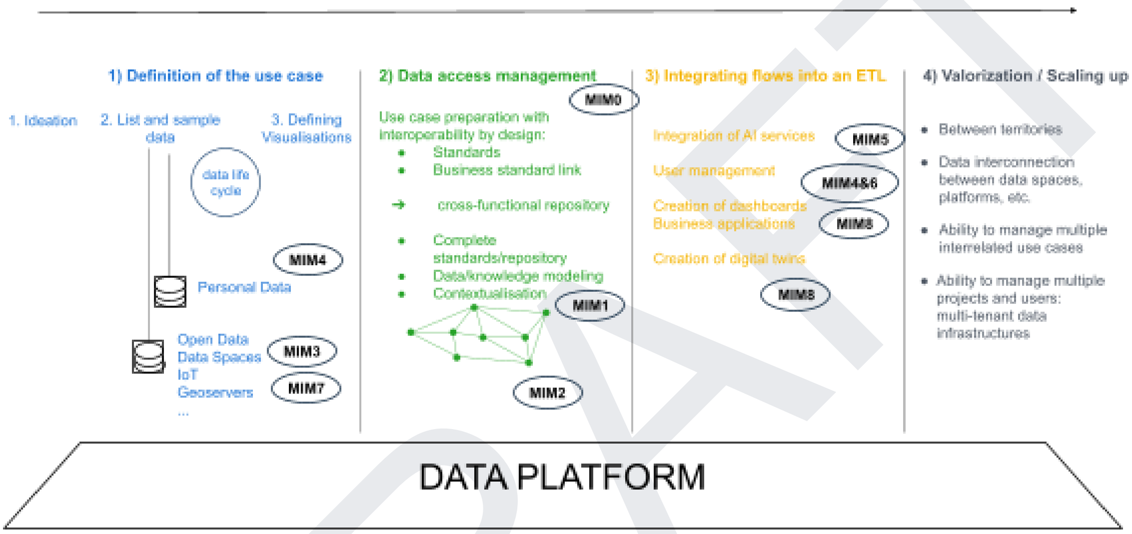

Figure 24. Overview of the step-by-step methodology in order to set up a use-case aligned with the MIMs Plus

7.3 AI services in the Work Strands

This section discusses the potential usages of AI with respect to the three different WS of LDT4SSC. It lists the available resources and solutions available on the market per WS, provides some initial guidance for pilot applicants, and highlights relevant partnerships within the European ecosystem in relation to digitalisation and LDTs.

AI plays a transversal role across all WS supporting predictive analytics, optimisation, scenario simulation, and advanced-decision support in the LDT ecosystem. In that context, does the challenge not only lie in the development of AI models, but also in their deployment capabilities as **operational services that are interoperable across platforms and aligned with European values and regulations**. While the functional role of AI is consistent –turning data into actionable insights– the relevance of supporting tools varies depending on the WSs.

WS1: Technical Interconnection of Data Platforms (Existing LDTs, Urban Data Dashboards…)

Here, one may use AI services to support cross-LDT analytics once data streams are interoperable. The main challenge remains the **interoperability of AI services**; indeed, as standardised serving protocols, such as the Open Inference Protocol (OIP), ensure that AI models developed in diverse frameworks (TensorFlow, PyTorch, Scikit-learn etc.) can be invoked consistently across connected LDTs, this interoperability is not a given from the start and must be worked towards. Working towards interoperability in the use of AI would as such guarantee the portability and reuse of solutions, allowing cities and communities to seamlessly share and invoke predictive or optimisation services.

WS2: Creation of LDTs Based on Common Needs

This Work Strand focuses on concrete urban policy challenges, such as mobility, energy, climate adaptation, and water management. While the AI functionality remains the same, the operational and citizen-facing use cases make **explainability, trust, and regulatory compliance (e.g. EU AI Act)** particularly important. Tools such as SHAP, LIME, and Alibi Explain support interpretability of model predictions while frameworks like AI Fairness 360 and Fairlearn help detect and mitigate bias. Transparency and accountability can be further strengthened with Models Cards and Datasheets for Datasets. Standardised model serving remains important, but these additional tools and frameworks ensure that AI-driven insights can be safely and transparently used in citizen-facing applications.

WS 3: Adding New Advanced AI-Based Tools to existing LDTs

This Strand focuses on the experimentation and integration of advanced AI approaches within already-existing LDTs, including generative AI, reinforcement learning, spatio-temporal modelling, and immersive simulations. As such, many tools can be thought of; below are a few we highlighted in the context of this Technical Landscape for Pilots:

- Kubeflow is an orchestration framework that can be used to manage complex experimental pipelines, including simulations and generative model training;
- MLflow tracks experiments and artifacts –where applicable.
- Frameworks such as PyTorch / TensorFlow and Hugging Face Transformers support the training and deployment of generative or predictive AI models.
- PyTorch Geometric (PyG) enables graph-based and spatio-temporal modeling, for example representing road networks, energy grids, or sensor relationships as graphs for advanced predictions
- For immersive and simulation-based AI, tools like Unity ML-Agents and CARLA allow for the testing of AI agents in virtual environments and urban scenarios. This combination ensures that experimental AI components are scalable, reproducible, and compatible with the LDT ecosystem.

We further developed a few recommendations for pilots in this section:

- **Guidance for LDT applicants**: Start with well-defined use cases and with semantically consistent high-quality data (leveraging NGSI-LD and Smart Data Models).
- Build AI models using widely adopted frameworks;
- Expose them as services via standardised serving protocols;
- Apply MLOps' practices to manage the lifecycle of the AI models, from the development phases to the deployment and monitoring ones.
- Incorporate explainability, governance, and compliance from the outset to ensure safe, trustworthy, and reusable AI services.

- **To ensure ecosystem connection**: All AI services should contribute to the LDT Toolbox and align with EDIC, MIMs and SIMPL to maximize interoperability, scalability, and adoption across European communities. This ensures that AI in LDTs evolves from isolated experiments into modular, reusable, and citizen-trusted services that enhance operational and analytical capabilities across Europe.

Table 4 provides a summary of the paragraphs above for quick reference.

Work Strand	Scope	Key Tools / Frameworks	Guidance for Applicants	Ecosystem Link
WS1 - Interconnection of Existing LDTs	Enable cross-LDT analytics, ensure interoperability and reuse	OIP, KServe	Develop models as interoperable services; ensure standardised serving	LDT Toolbox, SIMPL, MIMs, EDIC
WS2 - Creation of LDTs Based on Common Needs	Support operational and citizen-facing use cases (mobility, energy, water, climate), ensure explainability and compliance	SHAP, LIME, Alibi Explain, AI Fairness 360, Fairlearn, Model Cards/Datasheets	Ensure trust, fairness, transparency; deploy via standardised serving	LDT Toolbox, SIMPL, MIMs, EDIC
WS3 - Adding Advanced AI-Based Tools	Experimentation with generative AI, reinforcement learning, graph-based models, immersive simulations	Kubeflow, MLflow, PyTorch/TensorFlow, Hugging Face Transformers, PyTorch Geometric, Unity ML-Agents, CARLA	Use MLOps practices; track experiments; ensure reproducibility and compatibility	LDT Toolbox, SIMPL, MIMs, EDIC

Table 4. Overview of the different Work Strands' scopes, tools, and recommendations for the use of AI

Conclusion

Interoperability is central to the success of LDT deployments across the three Work Strands of the LDT4SSC project, and, as such, the enabling of seamless data exchange, collaboration, and value creation across diverse systems, sectors, and territories/local authorities. As a result and as thoroughly developed in this document, by adopting the "interoperability by design" approach and leveraging established frameworks such as the European Interoperability Framework (EIF), Minimal Interoperability Mechanisms (MIMs Plus), FIWARE components, tools from the LDT Toolbox, and data space architectures like Gaia-X and SIMPL, pilots can ensure legal, organizational, semantic, and technical compatibility, and hence interoperability amongst themselves in order to interconnect their LDTs to other LDTs or to other data spaces/ecosystems.

Building upon prior European initiatives such as DS4SSCC, SIMPL, the EU LDT Toolbox, and MIMs Plus, this document provides pilot applicants and those interested in LDTs with an overview of existing tools, standards, and best practices aligned with EU policies on data sovereignty, interoperability, and sustainability. Hence, this report is a resource to guide the design and deployment of interoperable, scalable, and sustainable LDT solutions.

As such, this report is a key output of Work Package 2 and Task 2.4 within the LDT4SSC project. It delineates the foundational technical landscape necessary to support pilots' projects focused on Local Digital Twins for Smart and Sustainable Communities, and each chapter contributes to this report:

- **Chapter 1** introduces the project's context and aims;
- **Chapter 2** highlights the critical role and challenges of interoperability in cities and communities;
- **Chapter 3** details data valorisation in territories/local authorities and presents the LDT4SSC meta-architecture for LDTs;
- **Chapter 4** reviews key European initiatives providing interoperability tooling;
- **Chapter 5** analyzes technical solutions and their maturity;
- **Chapter 6** explains methods for interconnecting LDTs;
- **Chapter 7** outlines deployment strategies for use cases and AI services;
- **The Glossary** clarifies essential terminologies;

Together, these sections compose a comprehensive technical landscape for pilot applicants to succeed in their projects.

The next steps after publishing this report involve using this report as the input for defining pilot perimeter and calls (WP3), supporting pilot execution (WP4), and informing the development of interoperability blueprints and reusable resources (WP5). This report will also feed into community engagement activities (WP2) to ensure pilots align with current technical standards and ecosystem needs. From a practical hands-on perspective, this report helps in establishing a foundation for pilots to adopt interoperable, standardised solutions, facilitating the replicability and scalability of Local Digital Twins across Europe, and thus contributing to a sustainable and innovative market beyond the project's duration

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