Ontologies for Urban Digital Twins

vCity Ontology: a human centred platform
for Urban Digital Twins

Eurocities Academy
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ARUP

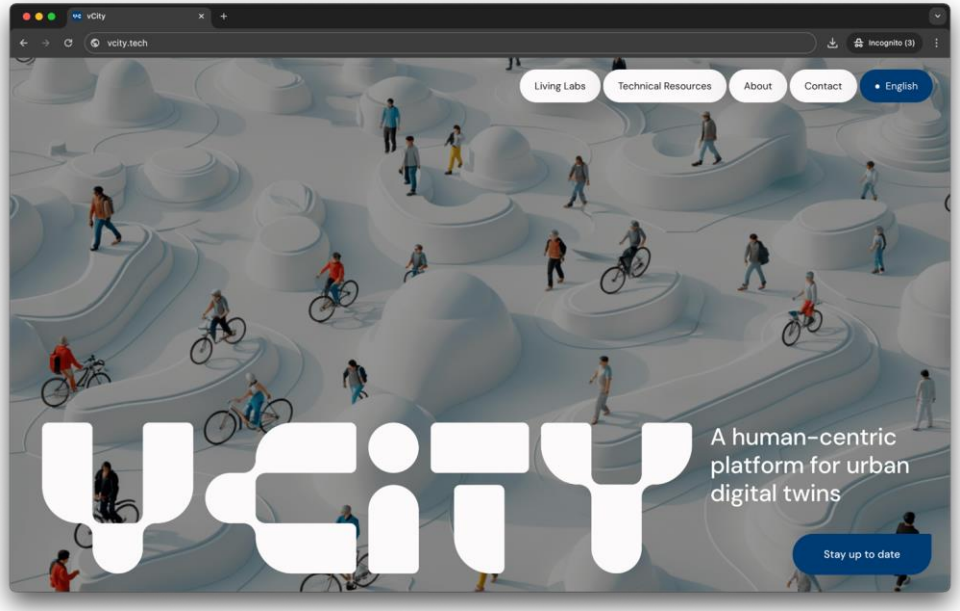
01

Introduction to ontologies

Why are ontologies relevant in urban digital twins?

As a shared language, ontologies:

1. **Provide a common semantics** for a set of heterogeneous data from the urban digital twin
2. **Facilitate interoperability between systems** for scaling UDT models as vCity to multiple cities
3. **Add explainability to the data** to aid the integration of data from various domains



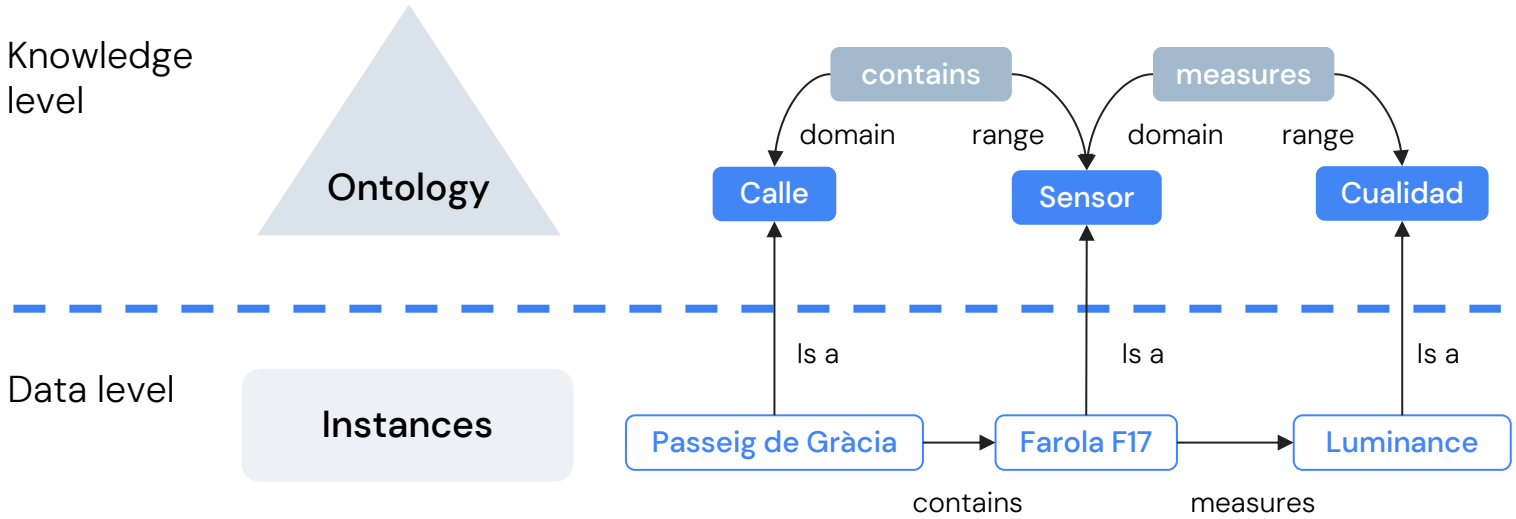
Ontologies structure of information: RDF

The basic unit of information in RDF is the triple.

SUBJECT	PREDICATE	OBJECT
URI	URI	URI or value

What is an ontology?

"An ontology is a formal and explicit specification of a shared conceptualization."



Studer, Benjamins, Fensel. Knowledge Engineering: Principles and Methods. Data and Knowledge Engineering. 25 (1998) 161-197

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Ontologies and urban digital twins

What do we understand by digital twin?

ISO/IEC 30173:2023

digital twin (DTw)

- digital representation of a target entity with data connections that enable convergence between the physical and digital states at an appropriate rate of synchronization
- Note 1 to entry: Digital twin has some or all of the capabilities of connection, integration, analysis, simulation, visualization, optimization, collaboration, etc.
- Note 2 to entry: Digital twin can provide an integrated view throughout the life cycle of the target entity.

target entity

- entity providing a functional purpose in reality which is the subject of digital representation
- Note 1 to entry: The target entity, which provides some functional purpose in reality, can be either physical or digital under consideration.

entity

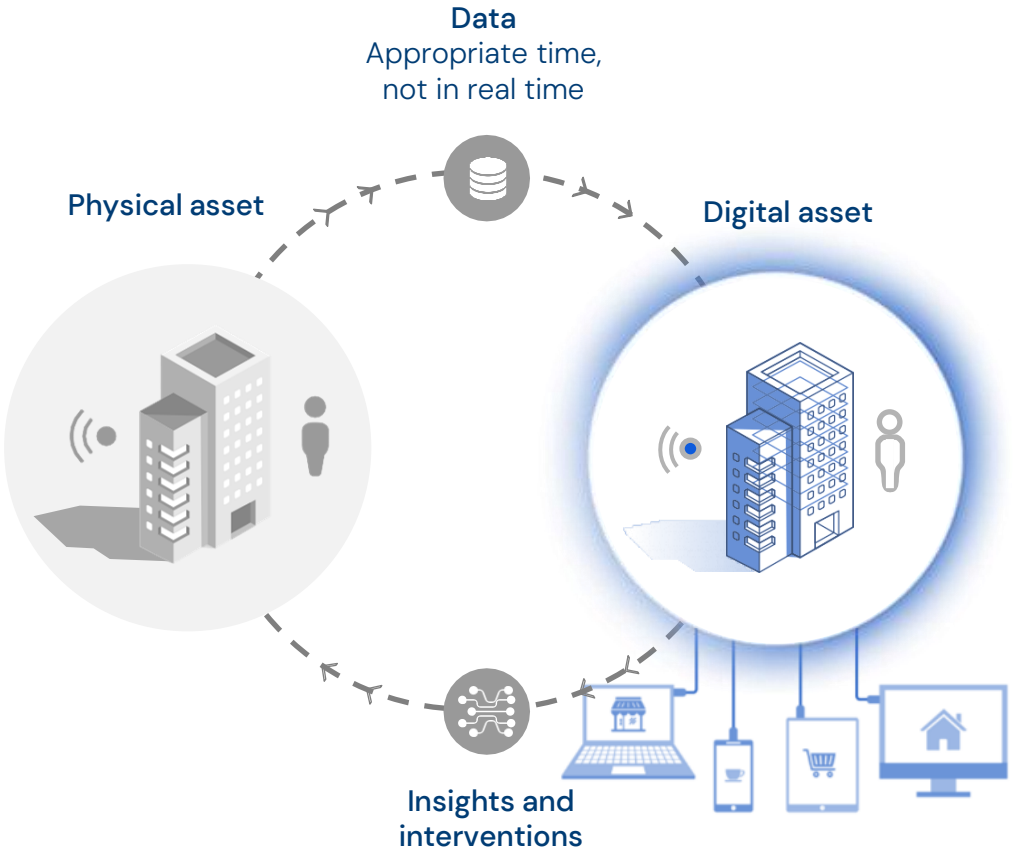
- <digital twin> thing (physical or non-physical) having a distinct existence
- EXAMPLE Person, object, event, idea, process, etc.

ISO/IEC 30173:2023. Digital twin – Concepts and terminology

Can the digital twin be a global database?

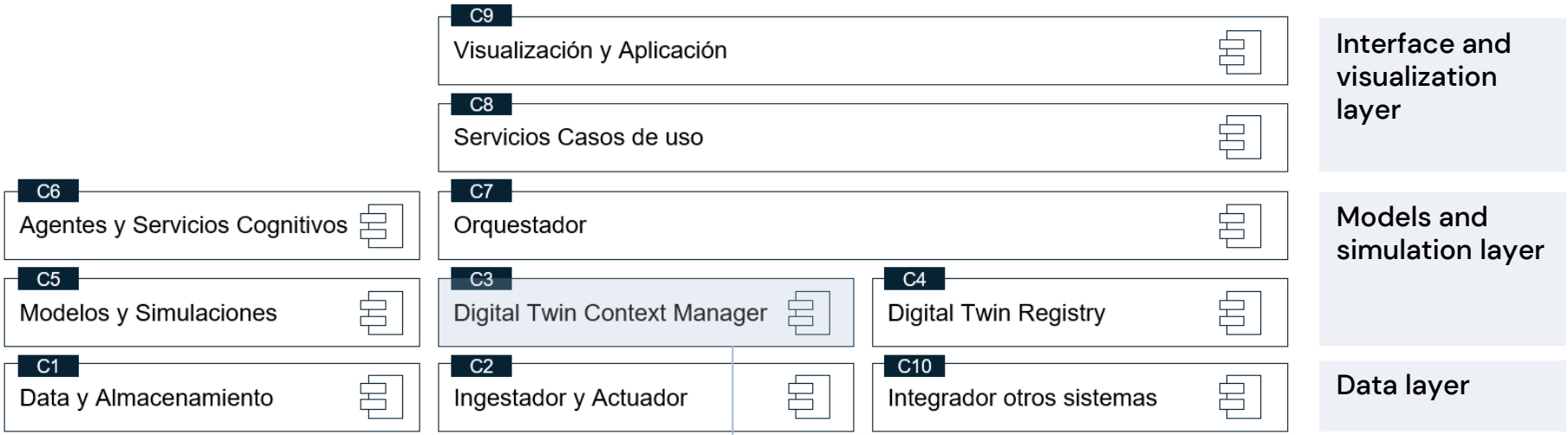
What is required?

- That infrastructures and cities have networks of sensors and actuators that allow for the **synchronization of the physical and digital** worlds.
- That digital twins include data spaces capable of integrating information from these sensors and actuators to **enable semantic interoperability** between a) data sources, b) digital twins, and c) other systems.



Integration within the urban digital twin

Arup reference architecture



Digital Twin reference architecture © Arup

Ontology and semantics
Ontology repository, graph storage engine, semantic query, RDF conversion, semantic enrichment, standard compliance

03

Methodology for the vCity project

Methodological proposal

Steps for the definition and development of the vCity ontology

01 **Analysis and requirements**

Define the purpose and the needs that the ontology must fulfill.

02 **Conceptual modeling**

Model the ontology in formal language according to defined requirements.

03 **Ontological development**

Generate computable models in OWL according to the modeling.

04 **Validation and testing**

Evaluate the ontology to identify errors and validate requirements.

05 **Documen-tation**

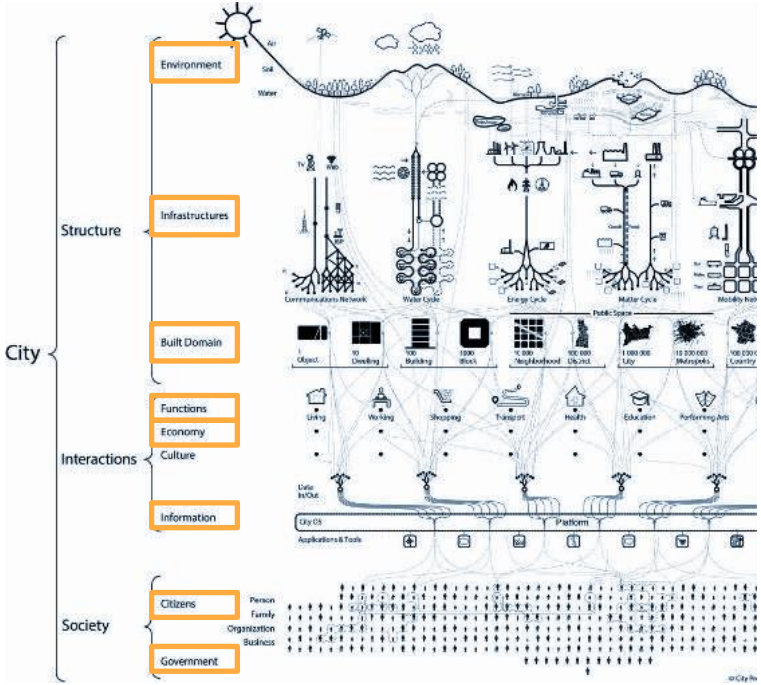
Document the classes and properties of the ontology prior to publication.

Initial considerations on the "vcity" ontology

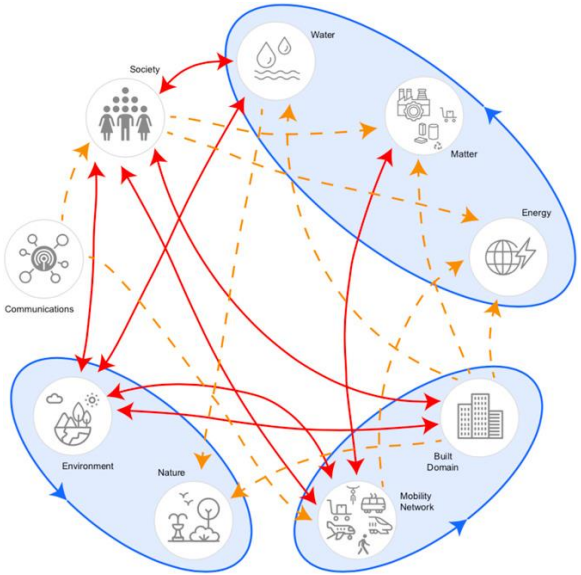
1. Urban approach and difference with smart cities.
2. Function as a semantic backbone.
3. Initial scope and first iteration.
4. Based on project data and expanded.
5. Reuse and alignment with existing ontologies.
6. Quality and alignment with international standards.
7. Governance and evolution of the ontology.
8. Technical interoperability and semantic alignment.

Conceptual framework of ontology

Linking with the conceptual framework of vCity



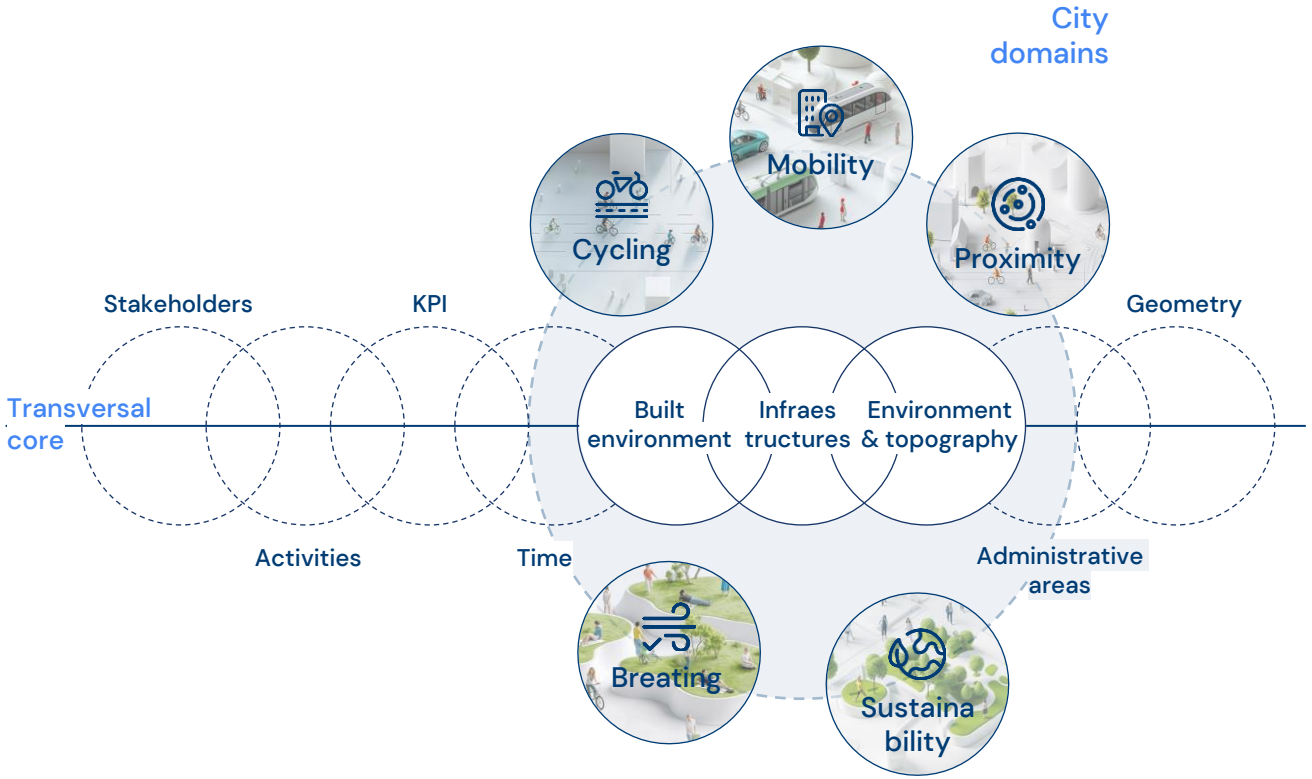
theoretical framework on how to simulate a city



Meta, I., Cucchietti, F. M., Navarro-Mateu, D., Graells-Garrido, E., & Guallart, V. (2022). *A physiology-inspired framework for holistic city simulations. Cities*, 126, 103553. https://doi.org/10.1016/j.cities.2021.103553

Domain and scope of the ontology

Requirements specification



Three key considerations for defining an ontology

Conceptual model

Requirements and domains

Standards

Ontologies reuse

Identifier (domain+id)	Domain	Competency Question / Natural language sentence (fact)	Answer	Status (Proposed, Accepted, Rejected, Pending, Deprecated	Superseeded by	Comments	Extracted from (provenance)	Priority (High, Medium, Low)	Subcategory	Linked vocabulary / ontology
mob-01	Mobility	What is mobility?	Mobility refers to the movement of people and vehicles across urban space using different modes of transport.	Proposed	–	Root class	vCity mobility use case	High	General definition	SAREF4City (s4city):Mobility, SKOS (concept scheme for modes)
mob-02	Mobility	What is pedestrian mobility?	Movement of people walking within the city, measured as flows, densities or counts.	Proposed	–	Base class for pedestrian flows	Mobility use case	High	Physical city element	s4city:PedestrianMobility, SOSA/SSN (counts), QUDT (units)
mob-03	Mobility	A pedestrian flow is characterized by count, density, location and timestamp.	–	Proposed	–	Defines attributes	Mobility use case	High	Transport modelling	SOSA/SSN (Observation → value, time, location), QUDT (count, density), GeoSPARQL (geometry), TIME
mob-04	Mobility	What is a vehicle?	A vehicle is a means of motorized transport such as cars, motorcycles, vans.	Proposed	–	Needed for private transport flows	Mobility use case	High	Physical element	TransmodelNeTEx (VehicleVehicleType), s4city:Vehicle, (optionally schema:Vehicle)
mob-05	Mobility	A vehicle flow is described by intensity, average speed, congestion index, and location.	–	Proposed	–	Attributes of traffic flows	Mobility use case	High	Transport modelling	SOSA/SSN (traffic observation), s4city:TrafficFlow, QUDT (speed, index), GeoSPARQL
mob-06	Mobility	What is traffic intensity?	The number of vehicles passing through a road segment per unit of time.	Proposed	–	Key traffic KPI	Traffic data, vCity	High	KPI	s4city:TrafficIntensity, SOSA/SSN, QUDT (veh/h), GeoSPARQL
mob-07	Mobility	What is congestion?	A state where road demand exceeds capacity, expressed as	Proposed	–	KPI	Traffic indicators	High	KPI	DATEX II (TrafficStatus/LevelOfService),
mob-08	Mobility	What is average vehicle speed?	The mean speed of vehicles in a corridor, in km/h, over a time	Proposed	–	Used for congestion assessment	Traffic data	Medium	KPI	SOSA/SSN, QUDT:Speed, TIME
mob-09	Mobility	What is public transport?	A shared system of mobility including metro, bus, tram,	Proposed	–	Mode class	Mobility use case	High	Physical element	TransmodelNeTEx (Network/Mode),
mob-10	Mobility	A public transport trip is defined by mode, line, station of	–	Proposed	–	Core attributes	PT datasets	High	Transport modelling	GTFS (Trip, StopStation),
mob-11	Mobility	What is a transport line?	A predefined path of a transit system (bus line, metro line, tram	Proposed	–	Structural class	PT data	Medium	Physical element	GTFS:Route, TransmodelNeTEx:Line,
mob-12	Mobility	A transport line is characterized by identifier, operator, stops/stations, schedule, mode.	–	Proposed	–	Attribute definition	PT datasets	Medium	Dataset attributes	GTFS (route_id, agency, stops), NeTEx (Operator, StopPlace, Timetables), DCAT (metadata)
mob-13	Mobility	What is a transport station?	A node where passengers can access, exit, or transfer in public transport (stop, station, interchange).	Proposed	–	Entity class	PT use case	High	Physical element	TransmodelNeTEx:StopPlace, GTFS:StopStation, GeoSPARQL, s4city:TransportNode
mob-14	Mobility	A transport station is described by identifier, name,	–	Proposed	–	Attributes	PT datasets	High	Dataset attributes	NeTEx/GTFS (served lines,
mob-15	Mobility	What is an Origin–Destination (OD) matrix?	A table showing the number of trips from each origin zone to	Proposed	–	Essential model	Mobility use case	High	Transport modelling	RDF Data Cube (QB) (matrix), SDMX
mob-16	Mobility	An OD matrix is characterized by origin zone, destination	–	Proposed	–	Attribute definition	OD surveys	High	Dataset attributes	QB/SDMX (dims: origin, destination,
mob-17	Mobility	What is interurban mobility?	Movements between the city and its surrounding territories.	Proposed	–	Subdomain	Mobility use case	Medium	General definition	s4city:InterurbanMobility, SKOS
mob-18	Mobility	What is a mobility survey?	A structured dataset capturing socio-demographic attributes,	Proposed	–	Source class	Surveys	Medium	Dataset	DCAT-AP (Dataset), QB/SDMX
mob-19	Mobility	Examples of mobility modes are: walking, cycling, private	–	Proposed	–	Enumeration	vCity	High	General definition	SKOS (mode taxonomy),
mob-20	Mobility	What is mode share?	The proportion of trips made by each transport mode relative to total trips.	Proposed	–	Derived indicator	Surveys, OD, sensors	High	KPI	s4city:ModeShare, QUDT:Percentage, QB/SDMX
mob-21	Mobility	What is modal shift?	The change in mode share over time due to interventions or	Proposed	–	Derived indicator	vCity simulations	Medium	KPI	s4city:ModalShift, QUDT (Δ%), TIME
mob-22	Mobility	What is travel time?	The time taken to complete a trip between origin and	Proposed	–	KPI	OD datasets	High	KPI	QUDT:Time, SOSA/SSN (observation),
mob-23	Mobility	What is accessibility in mobility?	The ease with which people can reach destinations via different transport modes.	Proposed	–	Cross-domain with Proximity	Accessibility models	High	Accessibility	s4city:Accessibility, GeoSPARQL, QUDT (minutes)
mob-24	Mobility	What is active mobility?	Mobility modes powered by human effort such as walking and	Proposed	–	Related to Cycling domain	vCity definitions	Medium	General definition	s4city:ActiveMobility, SKOS
mob-25	Mobility	What is motorized mobility?	Mobility modes powered by engines: private cars, taxis, buses,	Proposed	–	Category	vCity	Medium	General definitio	s4city:MotorizedMobility, SKOS
mob-26	Mobility	Mobility patterns can be aggregated by demographic attributes (age, gender, income).	–	Proposed	–	Relation to surveys	vCity	Medium	Transport modelling	QB/SDMX (demographic breakdowns), s4city:PopulationGroup, DQV
mob-27	Mobility	Mobility flows can be linked to emissions via vehicle type,	–	Proposed	–	Connects to Breathing domain	Traffic data	High	Cross-domain	s4city:EmissionFactor, SOSA/SSN
mob-28	Mobility	What is a mobility demand model?	A model predicting demand for different modes under various conditions.	Proposed	–	Simulation entity	vCity models	Medium	Transport modelling	s4city:DemandModel, PROV-O (Activity/Plan), SKOS (assumptions)
mob-29	Mobility	What is a mobility intervention?	A planned change in infrastructure, regulation, or incentives to	Proposed	–	Policy concept	vCity use case	High	Policy / Planning	s4city:Intervention, SKOS (policy type),

Defining the Competency Questions

Three key considerations for defining an ontology

Conceptual model

- **Requirements and domains**
- Standards
- Ontologies reuse

Cycling

Plan and implement an efficient network of cycle lanes.

Breathing

Rapid prediction of air quality changes due to urban interventions.

Mobility

Investigate the environmental and social impacts of different dimensions of multimodal transport.

Sustainability

Extend the circular economy index to high resolution for cities.

Proximity

Promote the proximity of services or points of interest to reduce transfers.

5 domains of the vcity ontology

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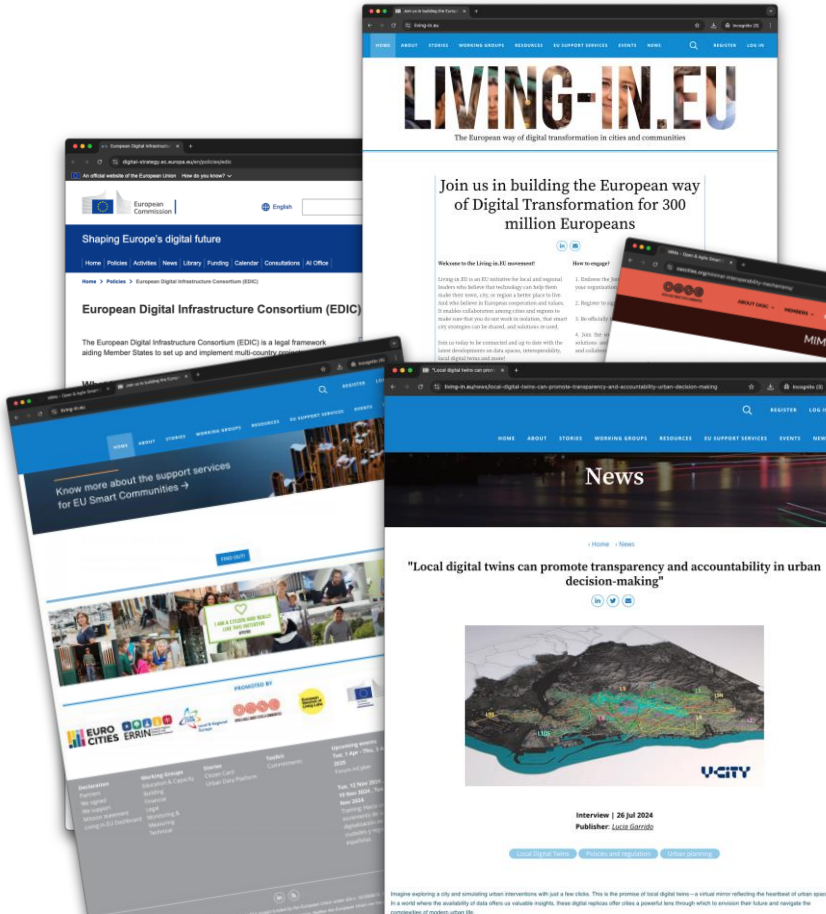
Ontologies reuse

- Minimum Interoperable Mechanism
- INSPIRE, EU Data Spaces, FIWARE, OGC
- Living-in.EU
  - Eurocities
  - CEMR
  - OASC
- EDIC Local Digital Twins
- AI Act
- CENT DT, W3C



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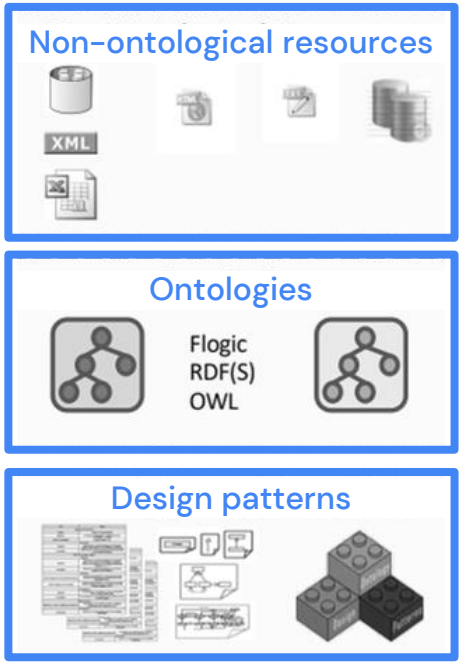

Time saving

Reaching agreements

Resource savings

Promotion of good practices

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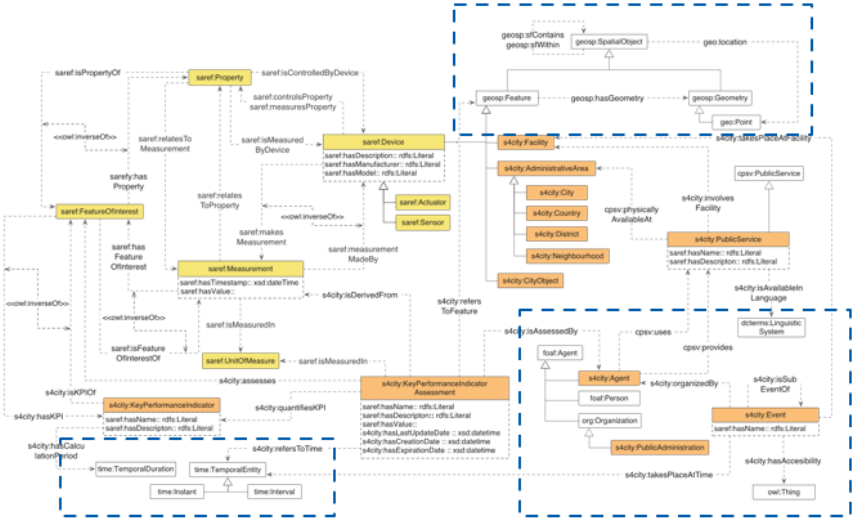
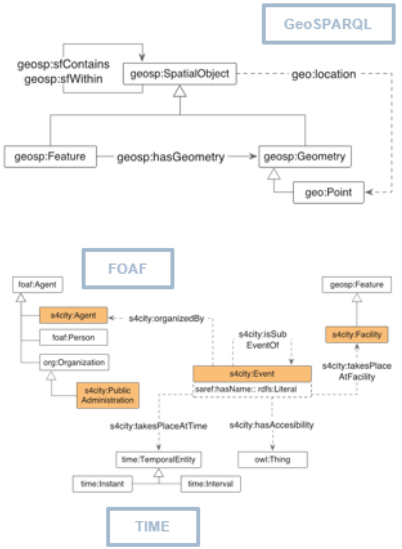


https://saref.etsi.org/saref4city/v1.1.2/



Key takeaways

Conceptual

1. Ontologies are the common language to enable the digital transformation of cities.
2. An ontology is not a database, but a model of meaning and knowledge.
3. The urban digital twin goes beyond a blueprint or a 3D model.

Methodological

1. Ontological development is an iterative and collaborative process.
2. There is no need to reinvent the wheel: other ontologies should be reused and standards should be adhered to.
3. Ontologies must be public, maintainable, and auditable. It is a living asset that evolves alongside the digital twin.

Thanks!

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