CityGML Energy ADE 3.0 Workshop 2026

Data integration in Urban Digital Twins: Challenge or key driver?

Imane Jeddoub, Rafika Hajji, Roland Billen

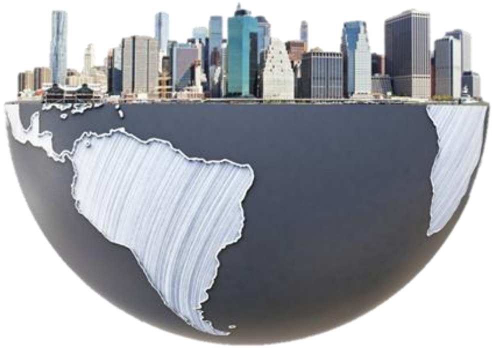
- Researcher at GeoScITY
- PhD in Geomatics
- Geomatics & Land Surveying engineer

Monday, 22 June 2026, 03:30PM - 04:00PM

TU Delft Pulse, Delft, The Netherlands

Lisence

BACKGROUND



Cities Major challenges

Population growth
Climate change
Disaster management
Improved living condition
Agriculture transition
Energy consumption

Sustainable Development Goals 11

Inclusive
Safe
Resilient
Sustainable
…

Digital technologies

Reality capture
Internet of Things (IoT)
Sensors/actuators
Artificial intelligence (AI)
Digital twins

BACKGROUND

Many Definitions…

- ❑ Too generic
- ❑ Too specific
- ❑ Not pratical
- ❑ Similar to existing concepts

Many "Twins" …

- ❑ Energy
- ❑ Mobility
- ❑ Environnement
- ❑ Urban planning

URBAN DIGITAL TWINS

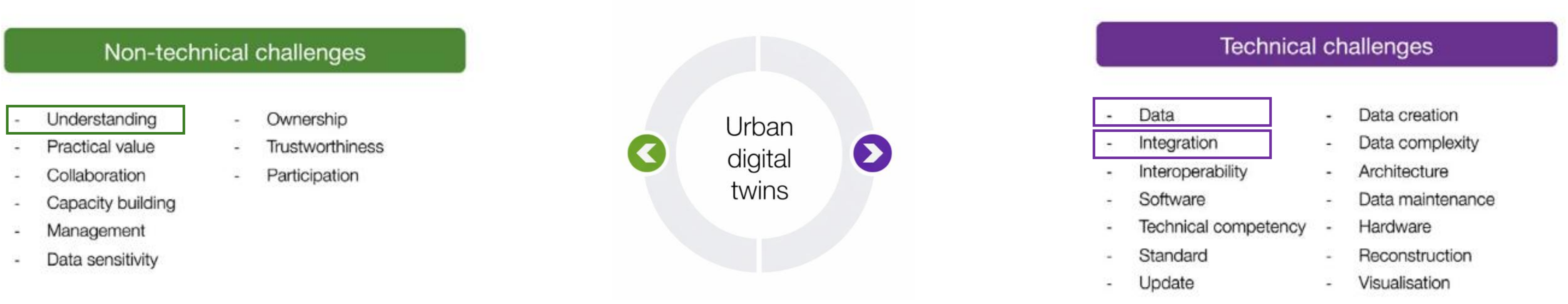
Many Stakeholders…

- ❑ Academia
- ❑ Industry
- ❑ Gouvernements
- ❑ Not-for-profit organisation

Many Challenges…

- ❑ **Non technical**
- ❑ **Technical**

MOTIVATION



@ Lei et al., 2023

DEFINITION

- ❑ Different fit for purpose definitions.
- ❑ Vagueness on the characteristics.
- ❑ Terminology ambiguity.

DATA

- ❑ Different time and spatial scales.
- ❑ Different forms and schemas.
- ❑ Incompatible systems (BIM-GIS).

INTEGRATION

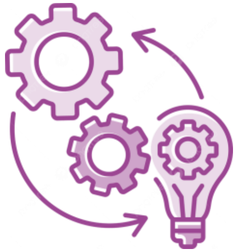
- ❑ Ineffective implementation.
- ❑ Heterogeneous techniques.
- ❑ Domain specific approach.

RESEARCH QUESTION

How can **Urban Digital Twins** be designed to **integrate heterogeneous data** while remaining **flexible** enough to **support diverse urban applications** and facilitate data **access and maintenance**?

Conceptual

Technical



CONCEPTUALIZATION

URBAN DIGITAL TWIN

HOW SHOULD A UDT BE DEFINED WITH RESPECT TO DATA INTEGRATION ?

An Urban Digital Twin is an up-to-date **semantic digital model** of the city and its subsystems that enables the **integration of heterogeneous real-world data** and the exchange between the physical and virtual worlds for monitoring, analysis, simulation, prediction, and decision support.

Main components

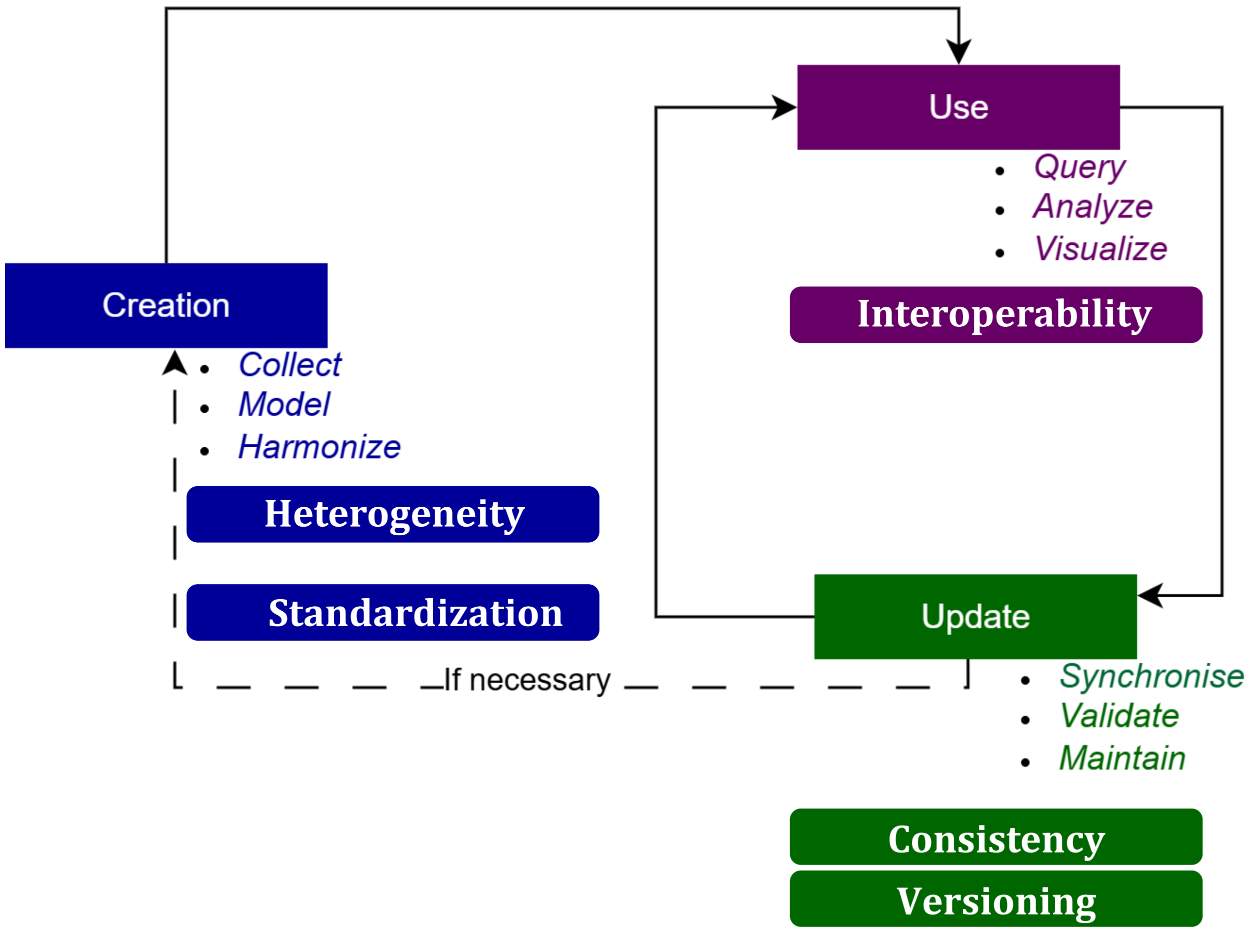
Semantic city model › **Multisource data** › **Bidirectional synchronization** › **Urban applications** › **Shared data platform**

Data integration is the core process that makes this definition operational.

Data Integration Challenges

What data integration challenges are specific to Urban Digital Twins?

A lifecycle-driven challenge



Main UDT-specific challenges

The challenge is continuous across the lifecycle.

1 Conceptual overlap

Digital Twins, model, platform: unclear boundaries around what "integration" covers.

2 Implementation heterogeneity

Different formats, tools, APIs, and domain workflows coexist.

3 Interoperability gaps

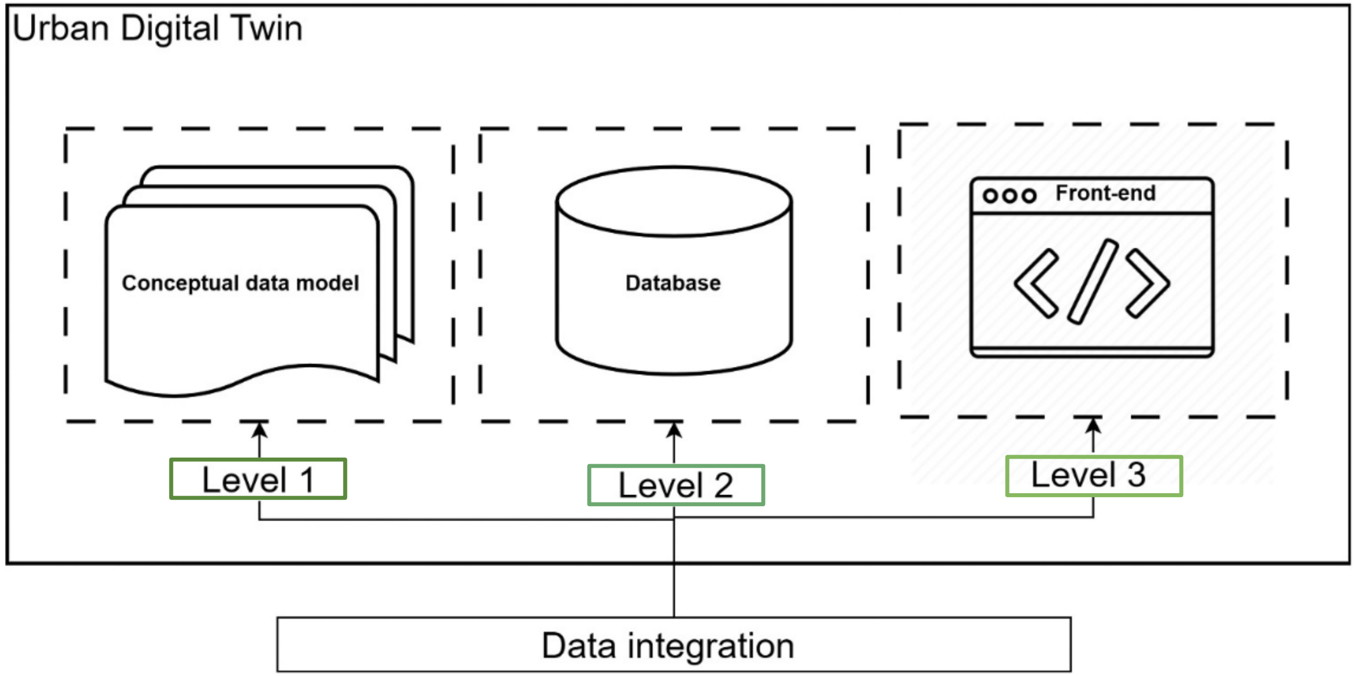
Semantic, spatial, and temporal mismatches hinder cross-domain reuse.

4 Update & maintenance

Validation, synchronization, versioning, and provenance become operational issues.

UDT LEVELS OF INTEGRATION

HOW CAN DATA INTEGRATION APPROACHES BE FORMALIZED ACROSS THE UDT LIFECYCLE?



Level 1 – Conceptual data model (CDM)

Schema-level integration: existing data models are **extended** to create a unified semantic model for the UDT.

Level 2 – Database (DB)

Data is **transformed** through ETL to fit the existing schema and database structure **without modifying** the conceptual data model.

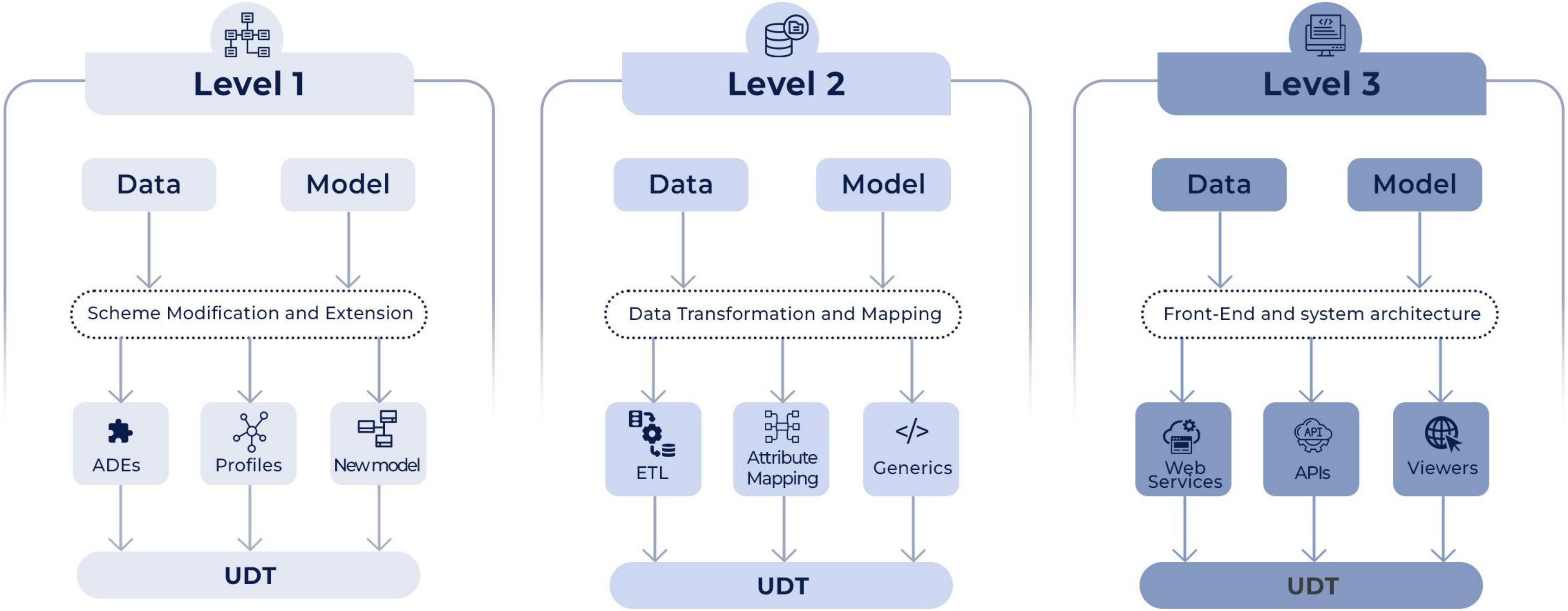
Level 3 – Front-end

Interface-level integration through web platforms, APIs, dashboards, or game engines to visualize and interact with multisource data.

From fragmented practices to a systematic integration framework

TOWARD A SYSTEMATIC INTEGRATION FRAMEWORK

HOW CAN DATA INTEGRATION APPROACHES BE FORMALIZED ACROSS THE UDT LIFECYCLE?



IMPLEMENTATION

Motivation

How can a UDT be developed to support different levels of integration in practice?

Challenges in practice

- Step-by-step UDT implementation guidance remains limited in the literature.
- Many projects show results, but not the design choices behind them.
- Limited openness, reuse, and reproducibility.
- Difficult updates, maintenance, and long-term evolution.

Technological decisions are often implicit, yet they shape interoperability and updates.

Key technological choices

1. Data model
semantic core, standards, and extension mechanisms.

2. Database / storage
schema rigidity vs lightweight flexibility and update logic.

3. Visualization / services
viewer, APIs, client-server architecture, and access mode.

These choices structure the implementation workflow.

Guided by

- Use case and target users.
- Available data and standards.
- Lifecycle and update needs.

Implications for UDT design

- A clearer and reproducible implementation workflow.
- Better alignment between technological choices and integration strategy.
- More interoperable, maintainable, and scalable UDTs.
- A stronger basis for updates across the UDT lifecycle.

KEY TECHNOLOGICAL CHOICES

HOW CAN A UDT BE DEVELOPED TO SUPPORT DIFFERENT LEVELS OF INTEGRATION IN PRACTICE?

Semantic standards

CityGML

- Rich semantic standard with ADEs.
- Structured domain modelling.
- Commonly encoded in XML.

CityJSON

- Lightweight and web-friendly JSON standard.
- Supports extensions and custom attributes.
- Easy to parse in browser-based workflows.

Two complementary standards: semantic depth vs a compact and developer-friendly alternative.

Storage layer

3DCityDB

- Mature CityGML ecosystem.
- SQL storage tailored to CityGML.
- Strong consistency and explicit schema.

CJDB

- Simple and lean CityJSON database.
- JSONB / PostgreSQL storage for CityJSON.
- Flexible updates and direct web consumption.

Database choice affects consistency, incremental updates, and query logic.

Visualization layer

Direct approach

- Direct retrieval from the database.
- Direct database client link and automatic reflection of updates.
- Better for management and incremental update workflows.

Indirect approach

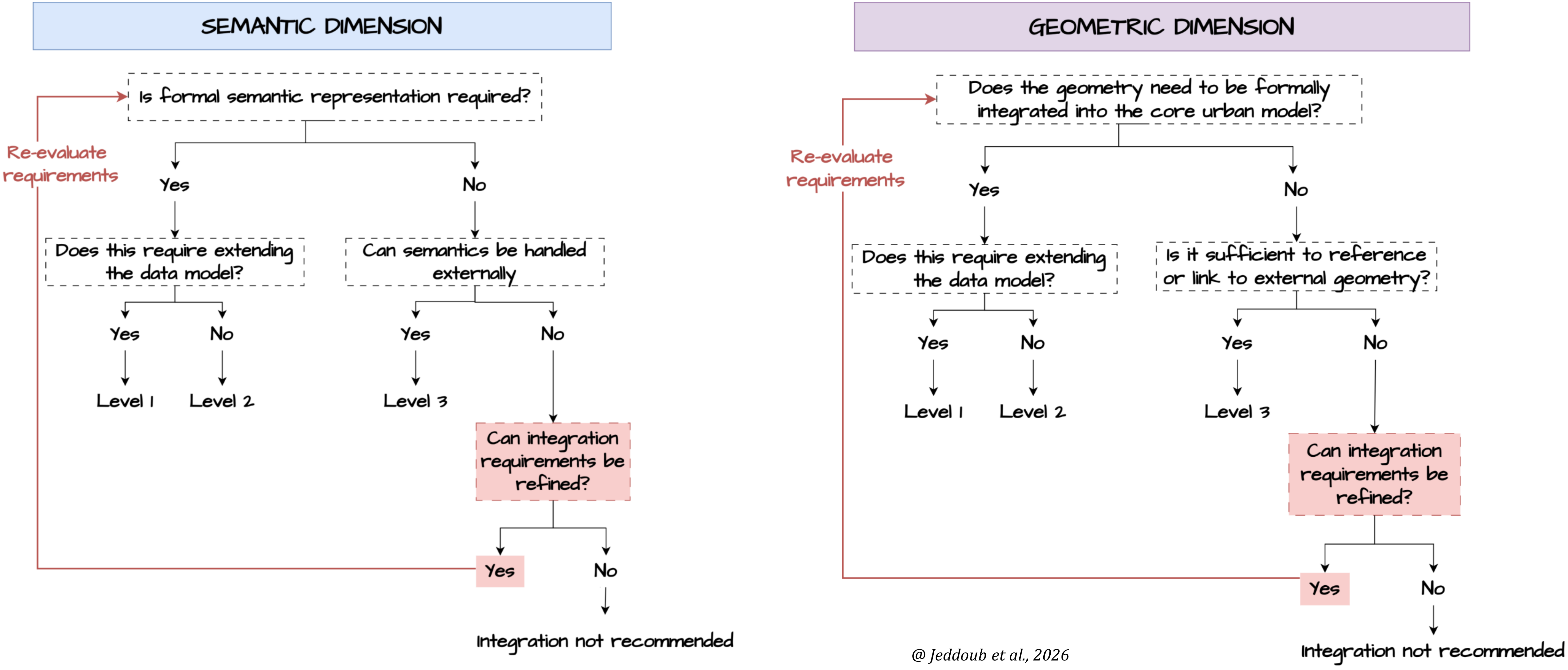
- Objects are exported, tiled, and hosted before visualization.
- Faster loading and streaming for larger scenes.
- Updates require re-export and reconversion.

Visualization choice defines web delivery, interaction, and update behavior.

Balance semantic structure with simple querying, incremental updates, and web delivery.

DECISION-SUPPORT FRAMEWORK FOR LEVELS OF INTEGRATION

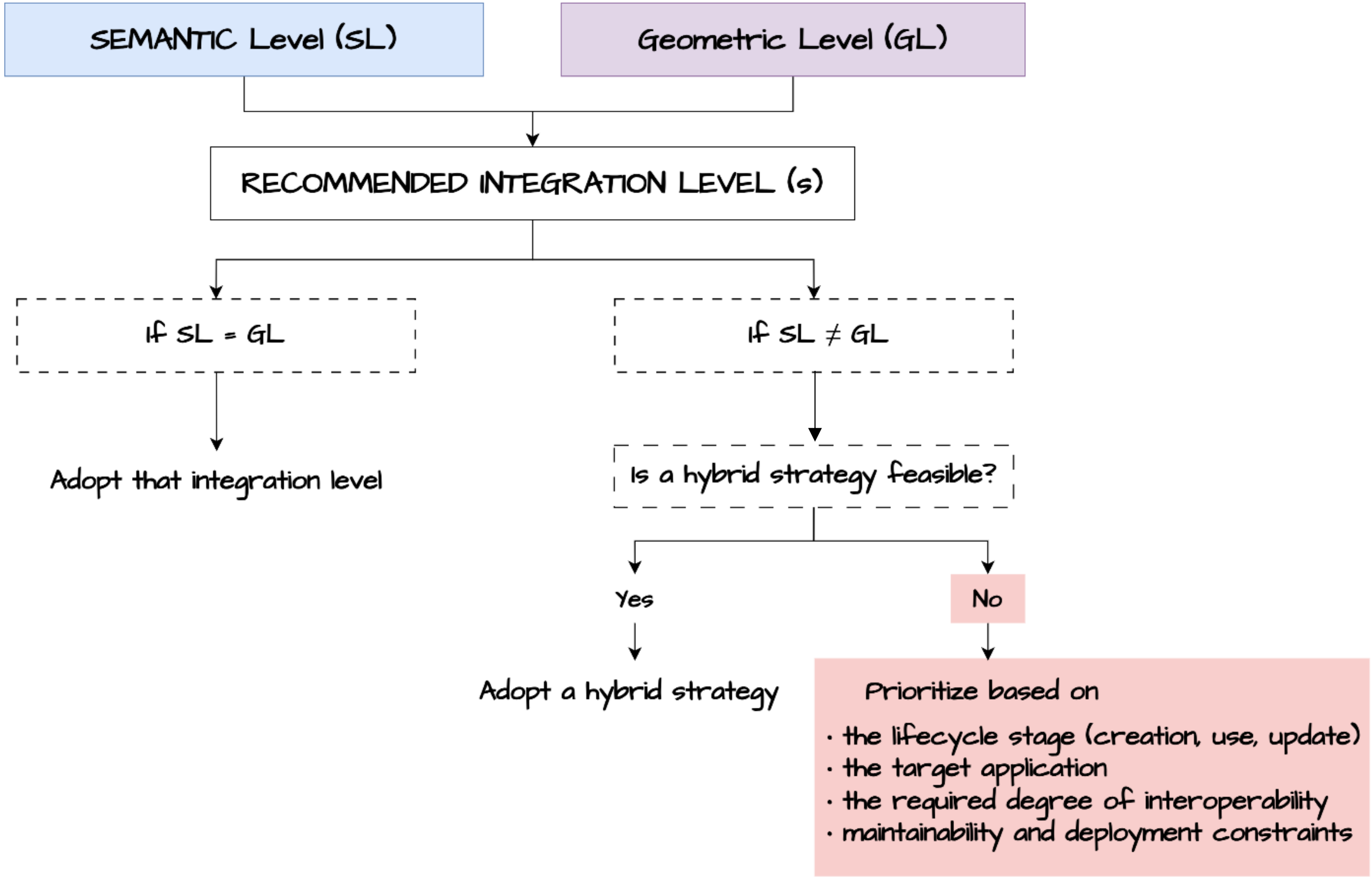
HOW CAN A UDT BE DEVELOPED TO SUPPORT DIFFERENT LEVELS OF INTEGRATION IN PRACTICE?



@ Jeddoub et al., 2026

INTEGRATION STRATEGY SELECTION FRAMEWORK

HOW CAN A UDT BE DEVELOPED TO SUPPORT DIFFERENT LEVELS OF INTEGRATION IN PRACTICE?



@ Jeddoub et al., 2026

Energy Use case :
The Hidden Role of Data Integration

MOTIVATION

40%

EU Energy Consumption

36%

Energy Related Emissions

55%

Required Emission Reduction by 2030

The European Renovation Crisis

1%

Current Annual Renovation Rate

3%

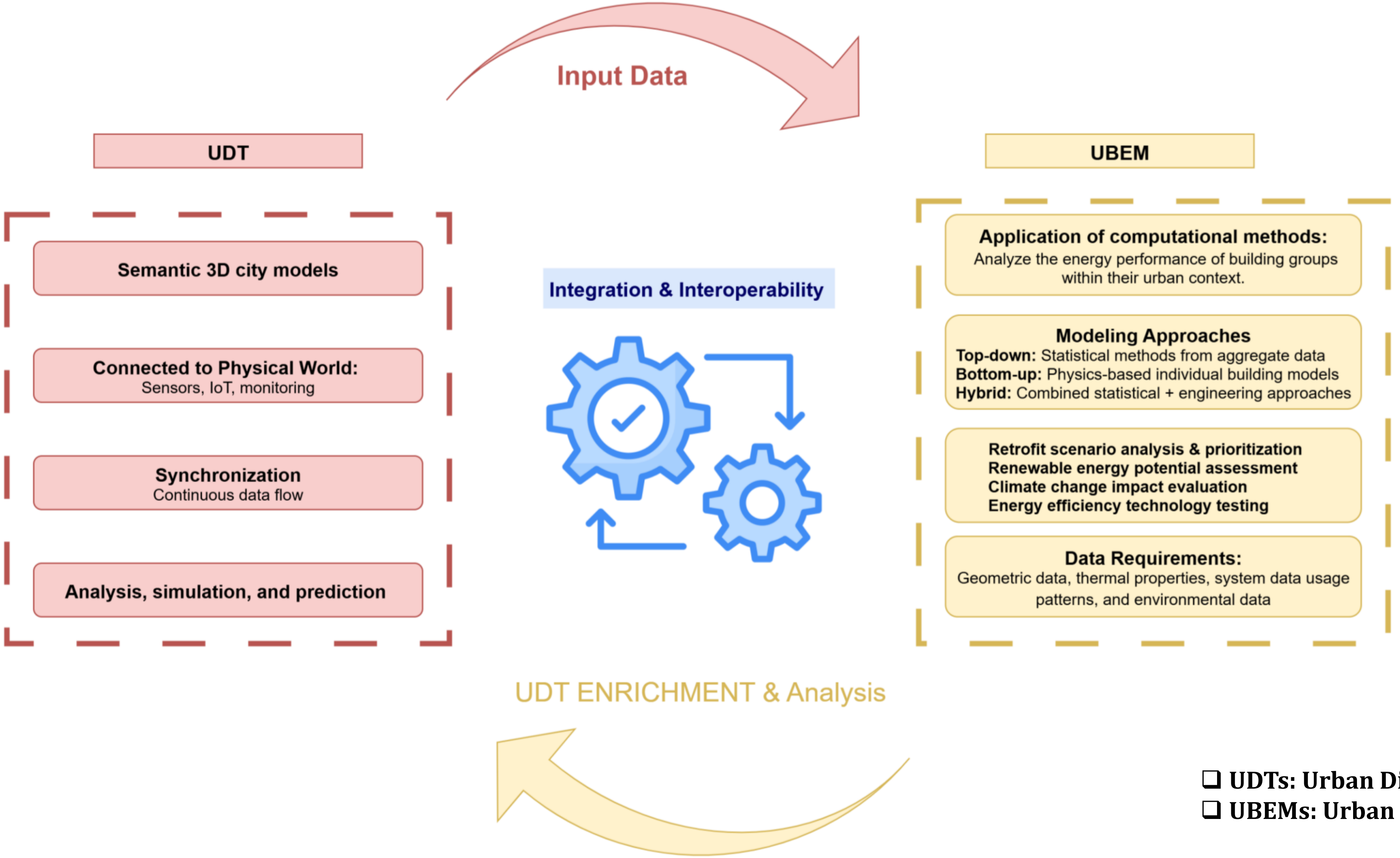
Required for Climate Goals

75%

Energy Inefficient Buildings

European Commission - *Energy Performance of Buildings Directive (EPBD)*
European Environment Agency (EEA) - *Buildings and construction*

UDTs and UBEMs Coupling



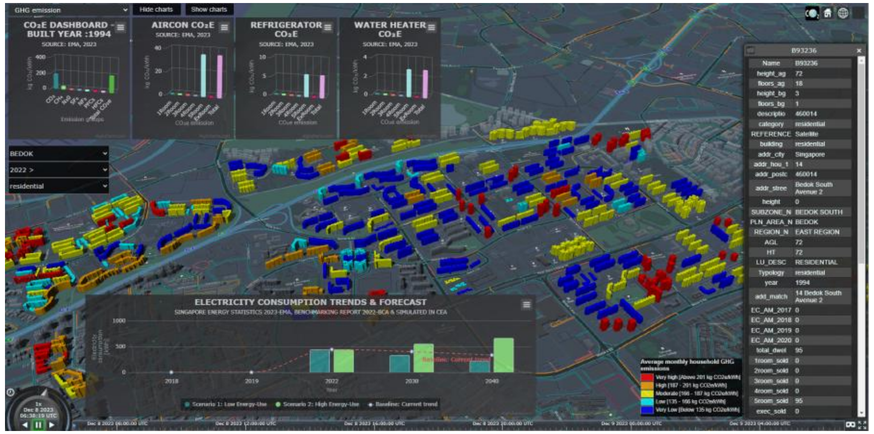
- **UDTs: Urban Digital Twins**
- **UBEMs: Urban Building Energy Models**

UDT PROJECTS FOR UBEMS

DigiTwins4PEDs

https://w2.iaf-ex.hft-stuttgart.de/DigiTwins4PEDs/Stuttgart/

UDT-GHG Dashboard



https://ghg.app.frs.ethz.ch/

EnSysLE Dashboard

https://transfer.hft-stuttgart.de/pages/ensysle/application/Ilm-Kreis/index.html

INTEGRATION APPROACHES

- ❑ **Level 1 - Conceptual Data Model:** Energy ADE (CityGML, CityJSON extension), Dynamizer ADE…
- ❑ **Level 2 - Database Level:** Generics, Existing extended data models…
- ❑ **Level 3 - Front-end Level:** OGC APIs SDIs, customized applications…

TEST CONFIGURATIONS

(a)HfT_Stuttgart_Campus.gml

- 8 buildings,
- 1 Functional Category,
- Construction Years(1870-2016),
- Height Range (11.3-29.0m).

(a)

(b)

(b) campus_liege.json

- 1667 buildings,
- 16 Functional Categories,
- Construction Years (1918-2025),
- Height Range (1.76-168m)

Level 1 – Energy ADE

Level 2 – Generics
Level 3 – Front-end

(c) SimStadt v2 tool (DIN V 18599)

- CSV file,
- Heat demand analysis
- ❑ Specific space heating demand (kWh/(m²·a))
- ❑ Domestic hot water demand (kWh/a)

(c)

(d)

(d) IDEAS Modelica library

- JSON files,

- Heat demand analysis (kWh/m²/year) :
- ❑ Specific heating demand (kWh/ m²)
- ❑ Specific cold demand (kWh/ m²)
- ❑ Electricity (MWh) and DHW (m³ /year) demands for each building identified by its unique ID.

SIMSTADT SIMULATION – LEVEL 1

CityGML

energyADE 3.0

Beta 7

Specifications

https://github.com/tudelft3d/Energy_ADE/blob/main/documentation/Energy_ADE_3.0_Specifications.pdf

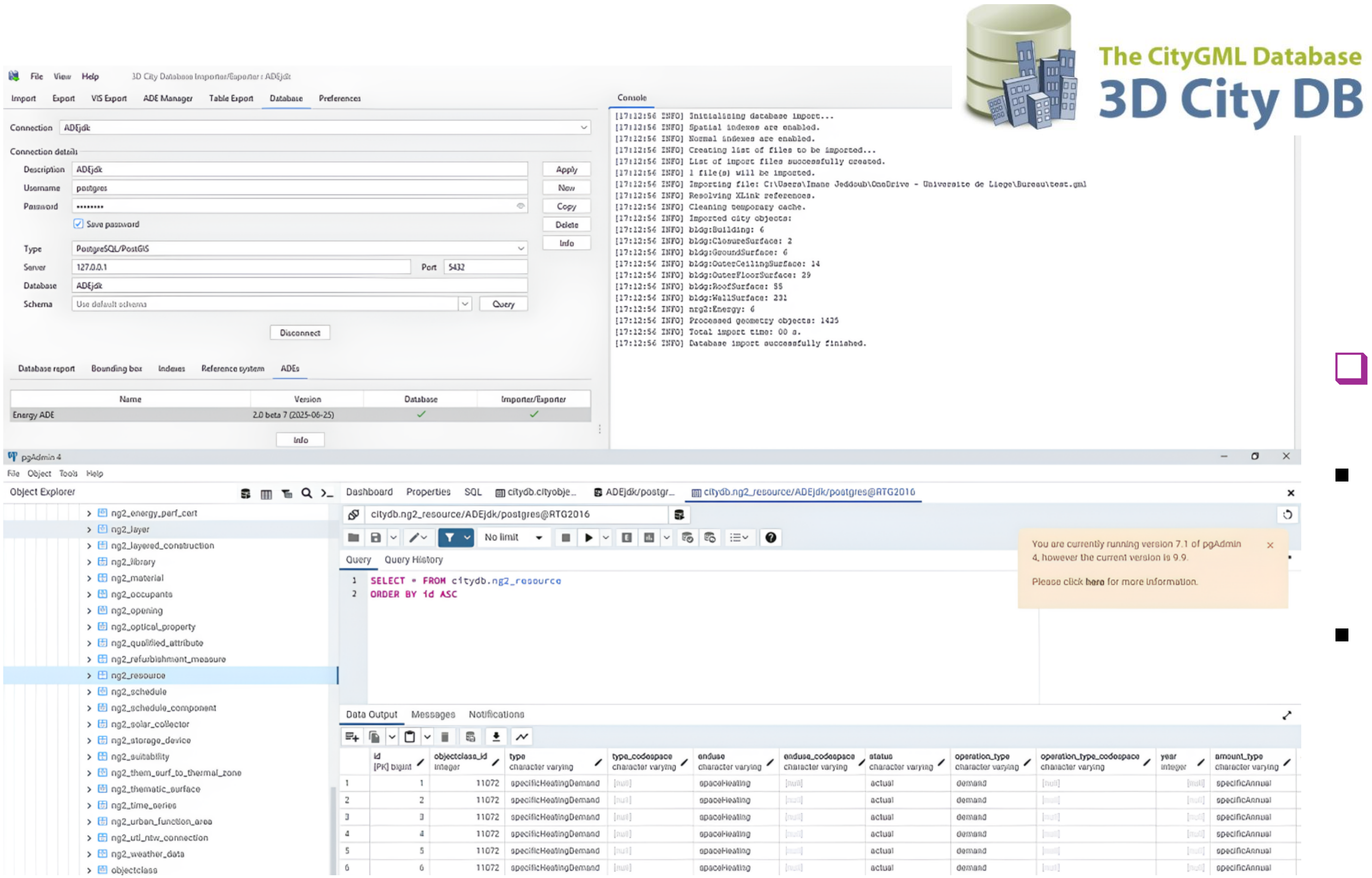
Implemented in October 2025

Beta 7 since October 2025

- ❑ UML diagrams
- ❑ Specifications document, modelling rules
- ❑ XSD file
- ❑ DDL scripts for the open-source database 3D City Database
- ❑ Test data
- ❑ Java-based libraries to support Web Feature Services

Beta 8 release - spring 2026

SIMSTADT SIMULATION – LEVEL 1



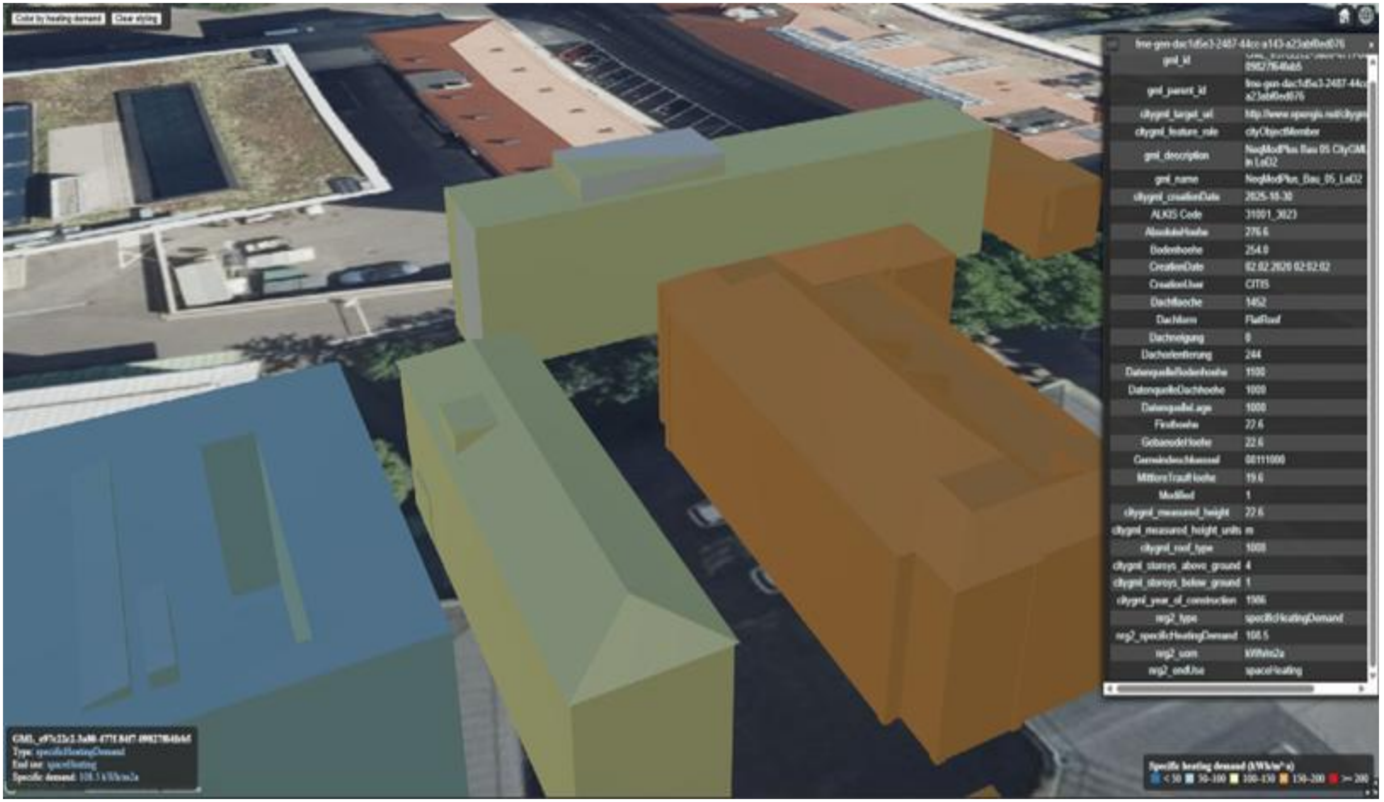
3D CityDB implementation

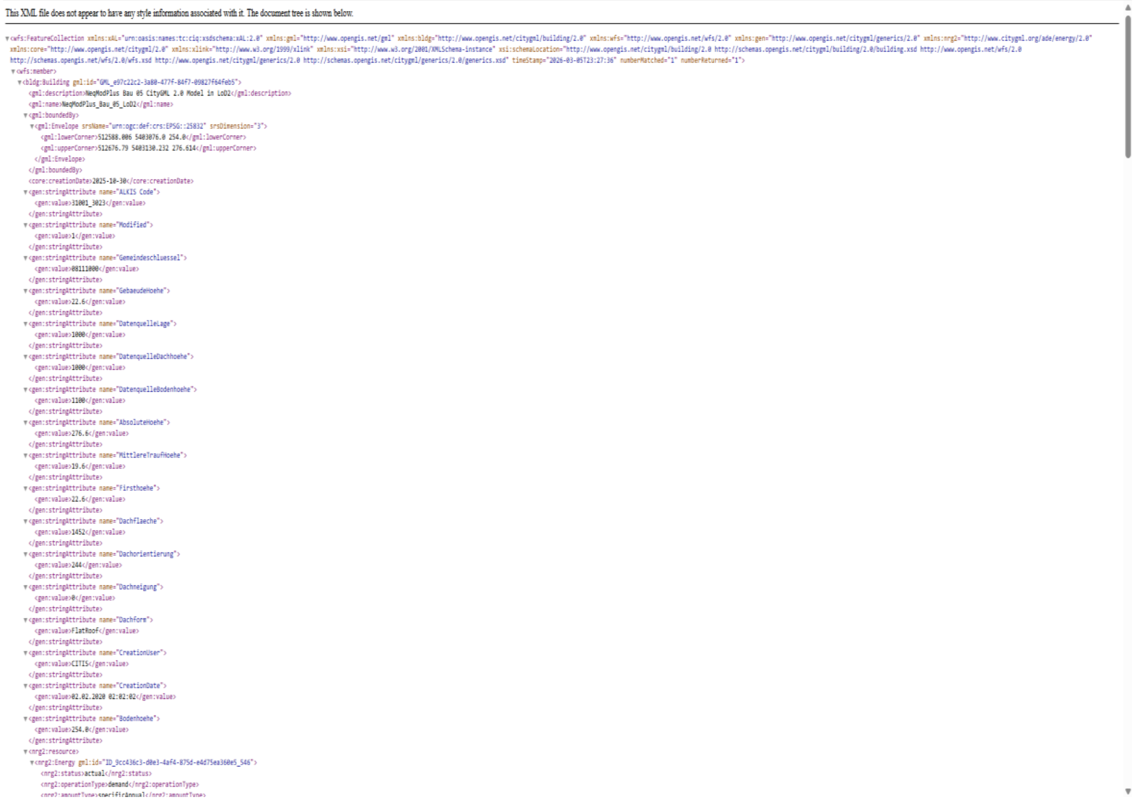
- ❑ **Visualization options considered**

- Map energy metrics to CityGML generic attributes for immediate color-mapped viewing.

- Expose Energy ADE Resources via OGC WFS, linked to buildings by gml:id for lightweight on-demand queries.

LEVEL 1 – ENERGY ADE





CityGML model with Energy ADE visualized in Cesium-based platform

Expose Energy ADE Resources via OGC WFS

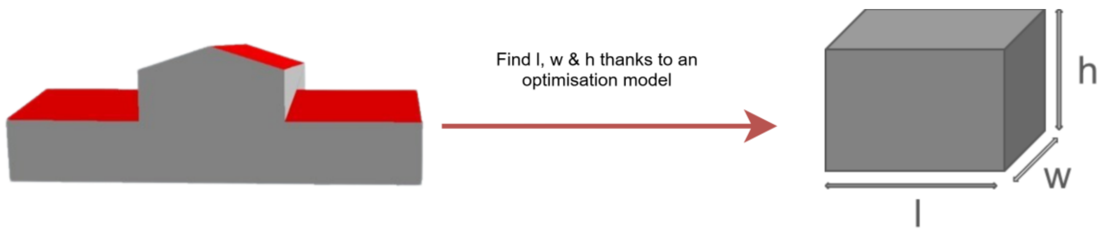
MODELICA SIMULATION

❑ Data preparation

- 3D reconstruction (Roofer)
- Enrichment (ETL pipelines)

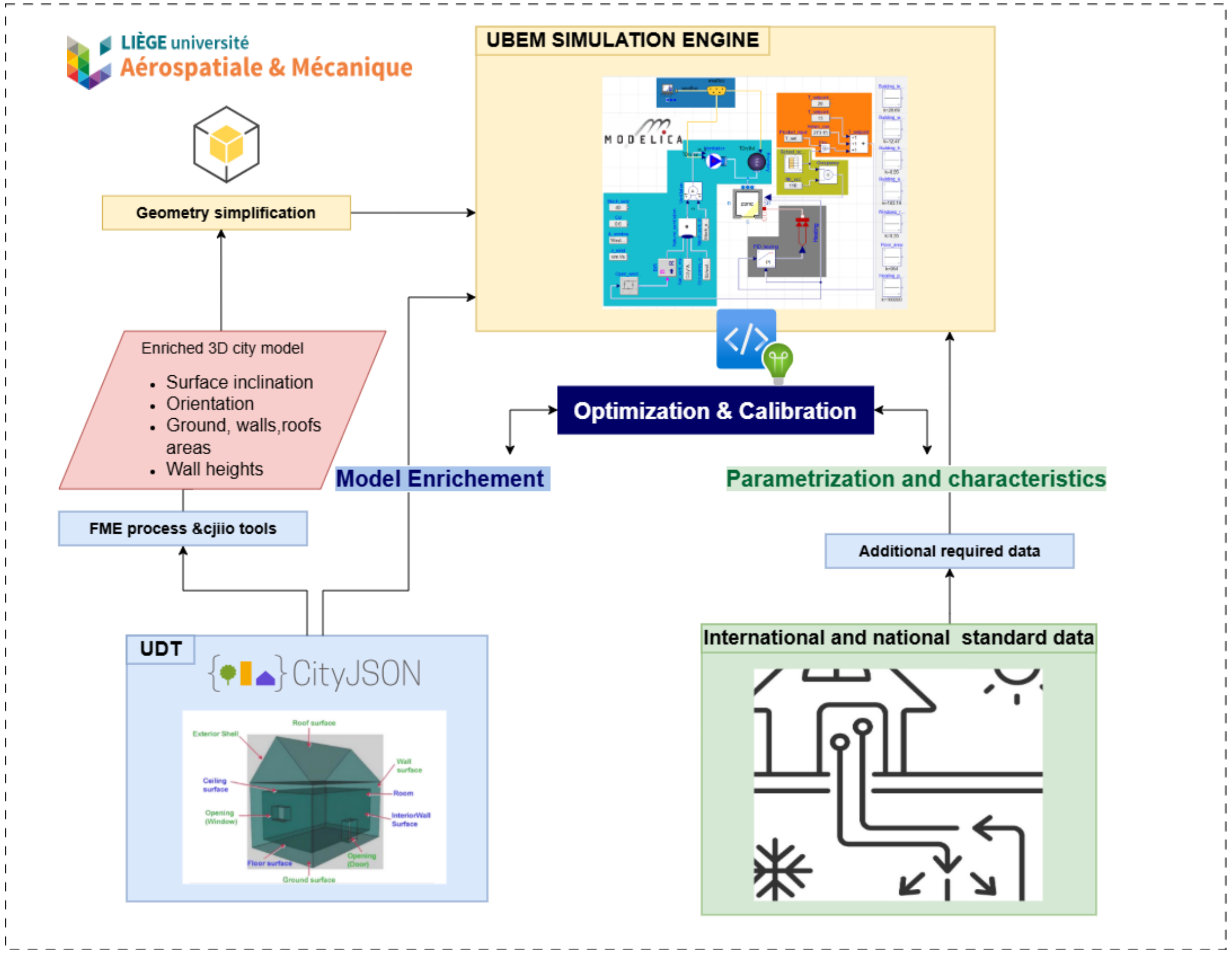
❑ Model optimization

- An abstraction is applied (complex geometries are replaced with rectangular parallelepipeds).



❑ Heat demand simulation

- Heating demand simulation (IDEAS Modelica library from KU Leuven within the Dymola simulation platform).



UDT Coupling With Modelica

LEVEL 2 – GENERICS

ETL pipeline

CITY2TWIN

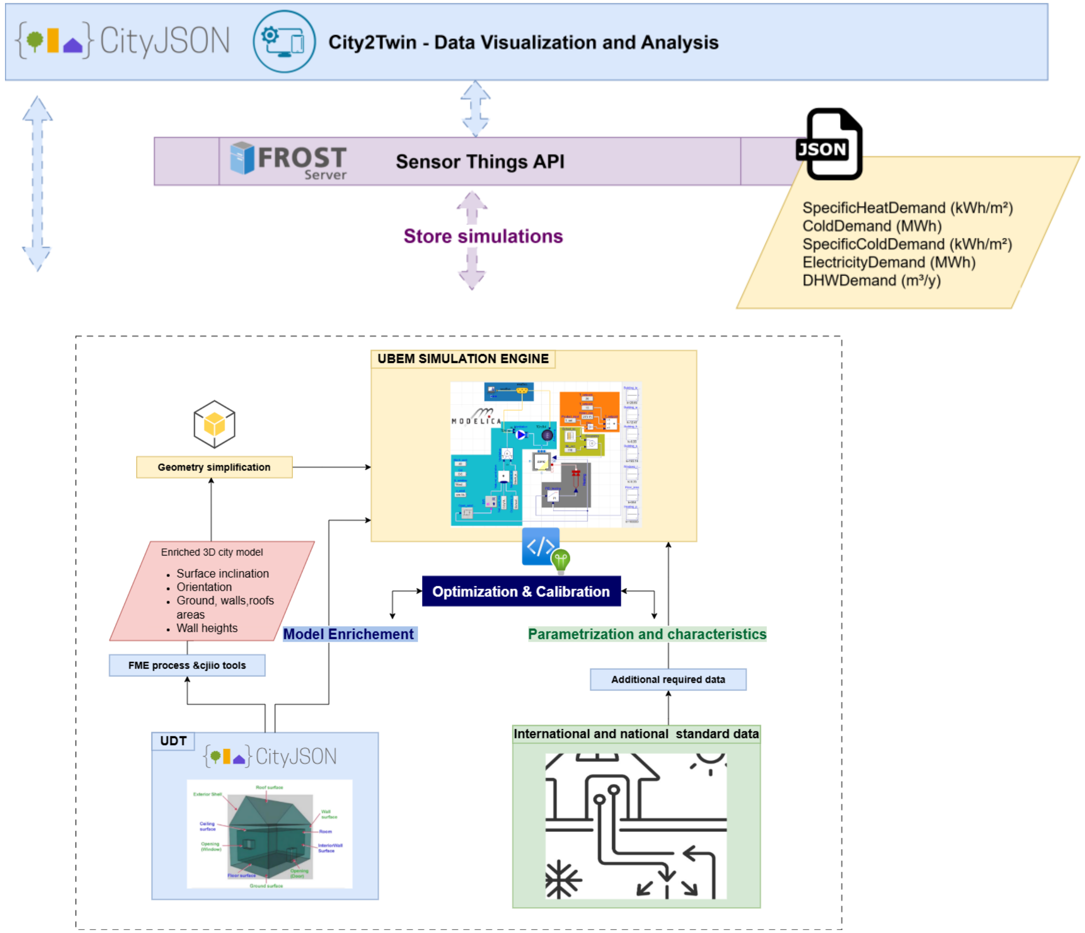
Client configuration

3D enriched CityJSON model using Generics

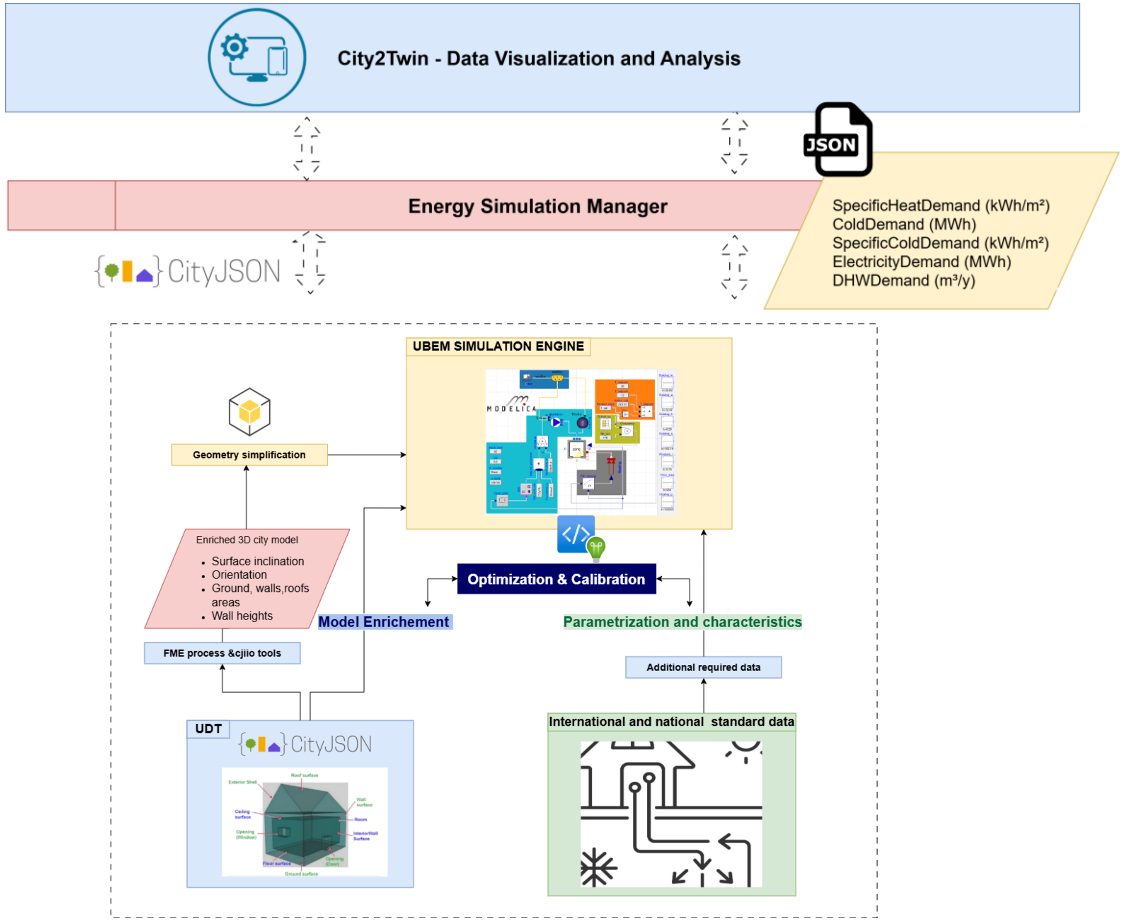
@City2Twin, GeoScITY

LEVEL 3 – STA VS CUSTOMIZED ARCHITECTURE

Sensor Things API Connection to UDT



Customized Energy Workflow



DEMO

Link to the videos→

https://www.geoscity.uliege.be/cms/c_12742331/en/geoscity-videos

Lessons Learned from the Implementations

01 Different levels, outputs, roles

- **L1:** consolidate rich semantic content
- **L2:** distribute lightweight, platform-ready snapshots
- **L3:** link external or live data on demand

The same use case can be implemented through different integration strategies.

02 No single level is always best

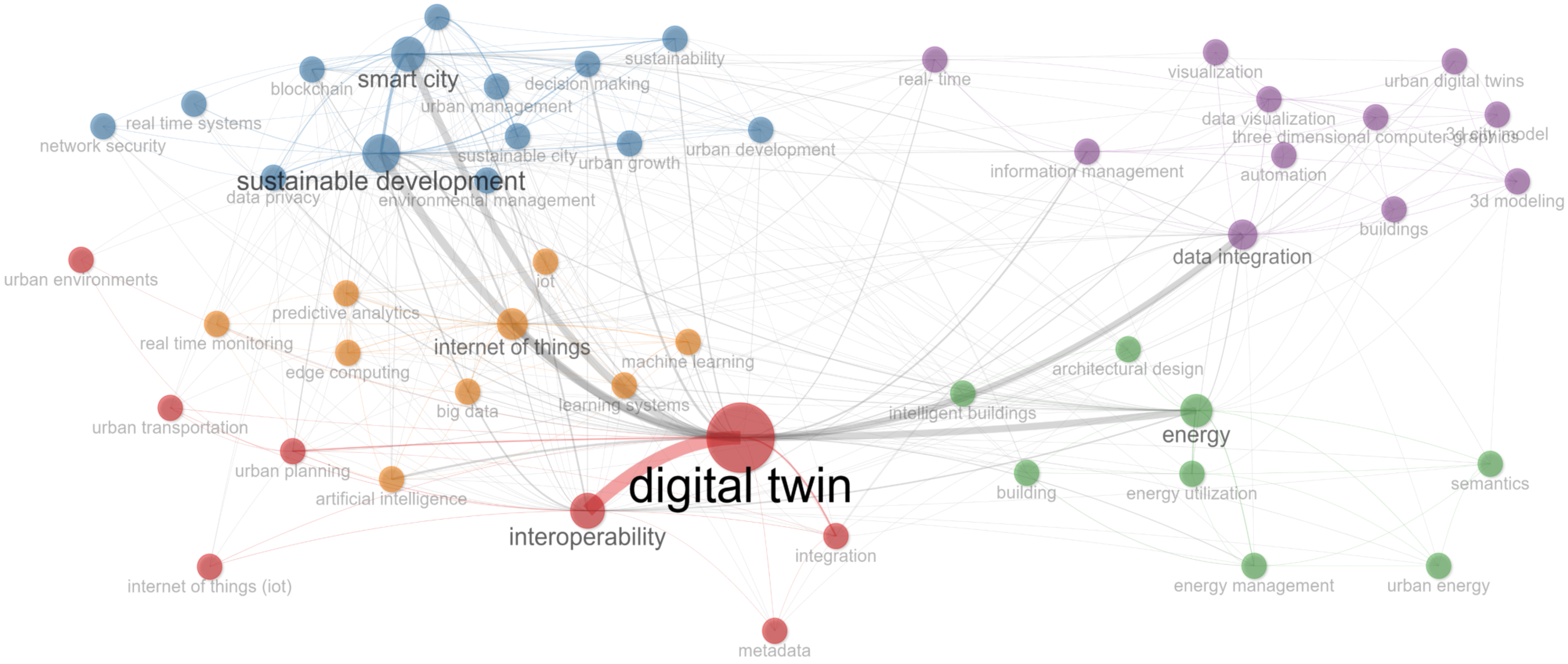
- **Choice depends on:** purpose and analytical depth
- **Guided by:** update strategy, access needs, and users
- **In practice:** software readiness and cost shape the decision

Levels are complementary choices, not competing solutions.

03 Needs for explicit rules

- **Stable IDs:** make cross-domain linkage possible
- **Validation:** must go beyond schema compliance
- **Update pathways:** must be planned and documented

Seamless integration works only when identifiers, mapping rules, and updates are clearly defined and controlled.



UDTs do not need more data.
They need better integrated and semantically enriched data.

CityGML Energy ADE 3.0 Workshop 2026

Data integration in Urban Digital Twins: Challenge or key driver?

Imane Jeddoub

Thank you for your attention!

Monday, 22 June 2026, 04:30Pm - 05:00Pm

TU Delft, Delft, The Netherlands

GeoScITY, ULiège, Belgium
i.jeddoub@uliege.be