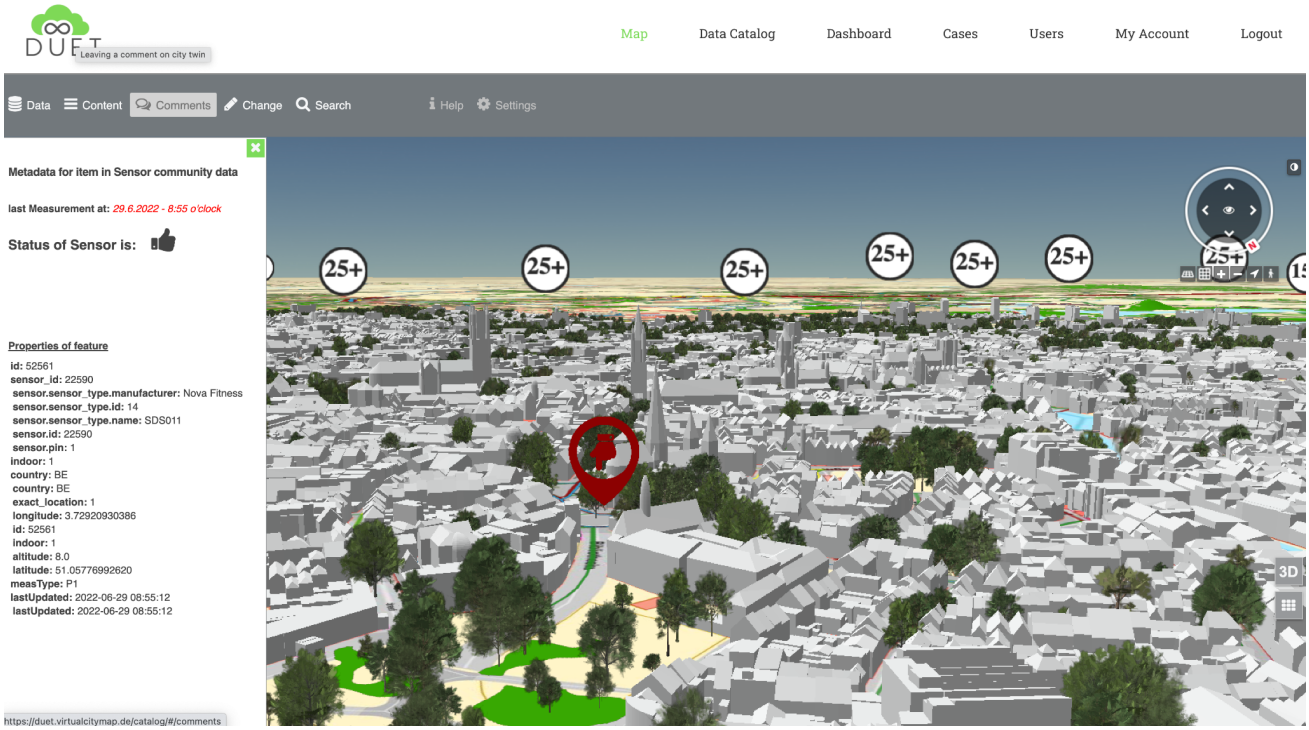
DUET Digital Twin - State of the art

Additional report on request of the EC



DUET Prototype depicting here an Integrated 3D city view, Live IoT data streams, traffic model simulation and planning zone visualisation to provide an integrated view of the city of Ghent (Belgium).

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1. Introduction and Summary

This report describes the current achievements of the DUET project and the need for further developments - describing the unique value proposition of DUET for establishing Local Digital Twins (LDT) in Europe and beyond. Based on the unique USPs, working prototype and proof of concept, DUET can become the basis of a genuine Local Digital Twin product ready to support European cities and regions.

DUET is unique in its open Digital Twin Architecture. Combined with slow- and fast-moving data and a simulation model catalogue that integrates multi-domain simulation modelling, it delivers a tool for policy prediction. DUET also offers the means to outreach to citizens and community groups.

This document has multiple goals. The first is providing an overview of the current components and TRL levels and the evolution needed toward TRL levels 7 (system prototype demonstration in operational environment) and 8 (system complete and qualified) of the DUET system.

The second goal is to reach these TRL levels by using open standards, open architecture principles and minimal interoperability mechanisms (MIM) to avoid vendor lock-in. The success will be dependent on how a digital twin allows interoperability between cities and regions and, at the same time, allow realising effective Digital Twin use cases aligned with local needs and investment budgets.

The third goal is to identify the remaining challenges in creating a network of cooperating simulation models. Central is a strategy for data processing and model interoperability and orchestration. The main elements of this strategy are the design of a unified approach toward model and data catalogues and a digital twin marketplace. Both need to be in alignment with advances in the field of dataspaces.

Another goal is to identify what is needed to integrate policy outcomes from a LDT into the public debate and decision-making process by using storytelling techniques, scenario presentations, and discussions that contribute to a higher level of public awareness and understanding. This goal forms probably the most society-oriented USP and purpose of the future DUET developments.

In that context, the document will also address the need for trust and transparency and ways to establish this. The technical integration challenges that DUET envisions to solve the need to be complemented with principles around reliability, openness and lineage of data used for policy-making. It will do so by proposing a smart data framework.

2. DUET Value Proposition to European Cities and regions

The DUET project delivers a combination of several value propositions that makes the DUET offering unique in the world. Especially the combination of several goals directed to delivering social goods combined with unique technical features and concepts provides a unique combination not available elsewhere today. It makes DUET an example of what a Local Digital Twin future product could look like.

From a societal perspective, DUET is unique in how it tested the Local Digital Twin concept of cooperation between policy domains in a quadruple helix setting in three entirely different locations in Europe: The Athens metropolitan area, the Belgian Flanders region of interconnected cities and Pilsen, a medium-sized city in Czechia.
From a societal perspective, the DUET supports:

- Cooperation in cities and regional administrations using each other's data and knowledge for calculating policy impact and policy-making;
- Cooperation between cities and regions in using each other's data and knowledge for policy-level overarching policy-making;
- Reaching out to local groups and citizens about the impact of policies on multiple policy sectors and domains;
- Combining all types of information (fast-moving IoT data, slow-moving static data, simulation modelling outcomes);
- Providing access to data from different providers (government data, private sector data and citizen science data);
- Providing better value for money of data investments (of taxpayer's money) through next-level GIS functionalities like 3D views on IoT and static city-data.

From a technical perspective, DUET also offers many unique value propositions:

- An open, scalable and replicable T-Cell architecture that combines genuine open source components to manage data and messages[1];
- Technical connection of advanced open visualisation clients, IoT data sources using open data catalogues, interoperable standards and protocols using the T-Cell;
- Connection with several (ten in total) cooperating simulation models used in the mobility, environmental and land-use fields from four different data providers;
- Use of well-known metadata and data standards in the geospatial field and beyond.

[1] See Deliverable D3.9: The T-Cell architecture pitches the (business) future of a digital twin marketplace, and thus aligns with the idea of digital twin "data spaces" where specific assets (data, compute, UX, ...) can be connected and assembled to rapidly create new digital twins covering specific needs. Connecting these assets will require further evolutions on standardization and best practices. This value proposition is crucial for the further success of the local digital twin ecosystem.

3. DUET stakeholder engagement

When it comes to LDTs, stakeholder engagement plays a role during solution development and its subsequent deployment. At the development stage, stakeholder input is needed to ensure that a Local Digital Twin meets the needs of its primary user group, which is usually policymakers. They must articulate their needs to the technical team, specifying what they want to do and see using an LDT.

Some cities will have climate neutrality high on the political agenda, so the use cases that focus on trends in and simulations of energy consumption and carbon emissions from traffic, built environment, land use, industrial processes, and so on would be a priority. Other cities might see LDT more like a decision support tool for emergency response, therefore prioritising real-time monitoring of water levels and the need for multi-model simulations involving waterways, urban transport, pedestrian flows and buildings. Whatever the use case, the involvement of end-users in the solution design over a series of testing and development cycles helps prevent a Local Digital Twin from becoming yet another data platform capable of producing great visuals but, in reality, is hardly ever used to solve real-life policy challenges.

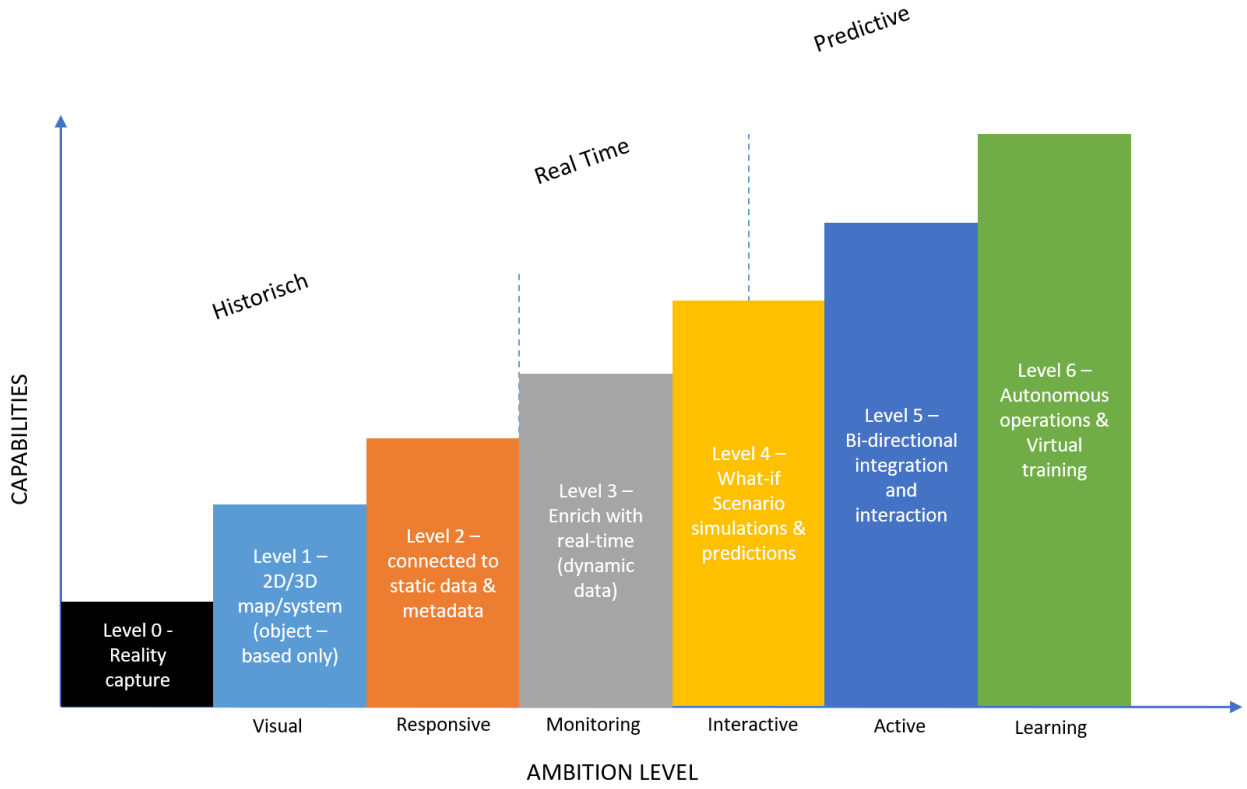

Figure 1: Local Digital Twin Ambition Levels

Once a Local Digital Twin becomes operational, stakeholder participation can move up a gear, but only in certain cases. This largely depends on the nature of a Local Digital Twin. Some LDTs are closed solutions used solely by governments. Some are open, and this type of 'network oriented' Local Digital Twin extends the traditional user base beyond policymakers.

DUET's platform, for example, can be accessed by anyone to see the impact of road closures on traffic and pollution in nearby streets (Pilsen), to find green routes for recreation and walking (Athens), or to understand

how pollution levels, both air and noise, change according to traffic volumes (Ghent). Other cities that opted for a network-oriented solution allow companies to improve their service offering based on climate data provided through the platform (Helsinki). And in Rotterdam, the ambition is to allow citizens to design urban spaces in a digital twin environment and then see the proposed changes in real life using an Augmented Reality app.

All these examples show that stakeholder engagement in the context of network-oriented LDT allows wider groups of urban stakeholders to become part of the vibrant, smart city ecosystem. Thanks to this Local Digital Twin type, citizens can have a much greater influence over policy processes rather than being on the receiving end of policy decisions. As they review, tweak and propose alternatives to original plans using a Local Digital Twin, not only does this help improve public policies, the actual link between government and civil society becomes stronger, as a result, leading to better governance and democratic outcomes for everyone.

4. The current status of DUET

In this chapter a clear distinction is made between user-oriented functionalities called epics.

4.1. Main functionalities

The DUET prototype offers a number of user-oriented numbered EPICs. The epics starting with a G+nr are generic and applied in all three pilots. The epics starting with A and P are only applied in Athens and Pilsen.

Nr	Epic
G1	**As a** public servant of a relevant department (mobility, spatial planning and environmental department,...) **I want to** see the difference in density of traffic in the area of interest of a scenario where I closed traffic in a set of roads versus the base density, **so I can** assess the impact of changes to the local situation on the traffic in my area of interest
G2	**As a** public servant of the mobility or environmental protection department, **I want to know** the level and impact on air pollution when certain roads would be closed **so I can** discover causes of air pollution and the impact on citizens well-being in the city
G3	**As a** public servant of the mobility or environmental protection department, **I want to know** the level and impact of noise pollution when certain roads would be closed, **so I can** discover causes of noise pollution and the impact on citizens well-being in the city
G4	**As a** citizen, **I want to** understand the predicted impact of different scenarios related to new city developments, calculated using functionality used for what-if analysis, **so I can** give feedback about scenarios
G5	**As a** citizen, **I want to** be able to vote and give feedback about scenarios related to new city developments,calculated using functionality based on other epics, **so I can** participate in those designs
G6	**As a** citizen, **I want to** see the current traffic flow in the city based on available sensors **so I can** inspect the current traffic density
G8	**As a** citizen, **I want to** see the current air pollution in the city based on available sensors **so I can** inspect the current level of air pollution
G9	**As a** citizen, **I want to** see the historic traffic flow in the city based on available sensors **so I can** inspect the historic situation and evaluate the impact of past measures
G11	**As a** citizen, **I want to** see the historic air pollution in the city based on available sensors **so I can** inspect the historic situation and evaluate the impact of past measures
G13	**As a** citizen, **I want to** express interest as a volunteer tester scenarios of cases proposed by the city **so I can** validate the expected results and contribute prior to the actual implementation.
G14	**As a** citizen, **I want to** have the possibility to contribute with data I can collect, **so I can** provide more data sources **(only services)**

G15	**As a** DUET admin, **I want to** be able to **connect** datasources **so I can** be sure that the necessary data and information is available
G16	**As a** DUET admin, **I want to** be able to **restrict** the access to datasources **so I can** be sure confidential data is not made publicly available
G17	**As a** citizen, **I want to see** only the datasources that are public **so I** don't see confidential information
G18	**As a** DUET admin, **I want to** be able to monitor platform status **so I** can adjust resource allocation and investigate logged errors or misuse
A1	**As a** city official, **I want to** see the public transport in the city based on static datasets (Urban transport datasets includes timetables, routes and locations of stations) **so I can** assess the situation and elaborate on new strategic plans for interconnecting public transport
P1	**As an** urban planner **I want** to see all existing attributes for buildings and objects in 3D representation of the city **so I can** work with different data sources in a single environment
P2	**As an** urban planner **I want** to see all existing attributes for public space such as surfaces, public green, tree informations (tree type, height, diameter of trunk, diameter of treetop) **so I can** work with different data sources in a single environment
P3	**As an** urban planner **I want** to see Z dimension for all objects and surfaces (streets, pavements etc.) **so I can** work with the z dimension as it is not supported by current GIS solution used by city.
P4	**As a**n urban planner **I want** to style object based on available attributes **so I can** make custom analyses and visualisations

Table 1: DUET User-oriented functionalities translated into epics

4.2. DUET architecture status

4.2.1. Explaining the T-Cell concept

The DUET T-Cell architecture is designed as a plug-in interface to support all these functionalities. It exposes a message broker API that allows the components to connect to the T-Cell's internal *message streaming system* on which all data flows between the different components. Other APIs can be used to manage the registration of components (asset catalogue) and the management of cases and scenarios (case manager) and also the management of the system and security.

The ultimate goal of the DUET architecture is to allow data sources, models and even digital twin client applications to be reusable and generic across different LDTs or in different cities. Creating a scalable marketplace for Digital Twin Components and Assets, including governance, will be essential. More information can be found in the DUET Deliverable 3.9 (Michiels & Vervaet, 2021).

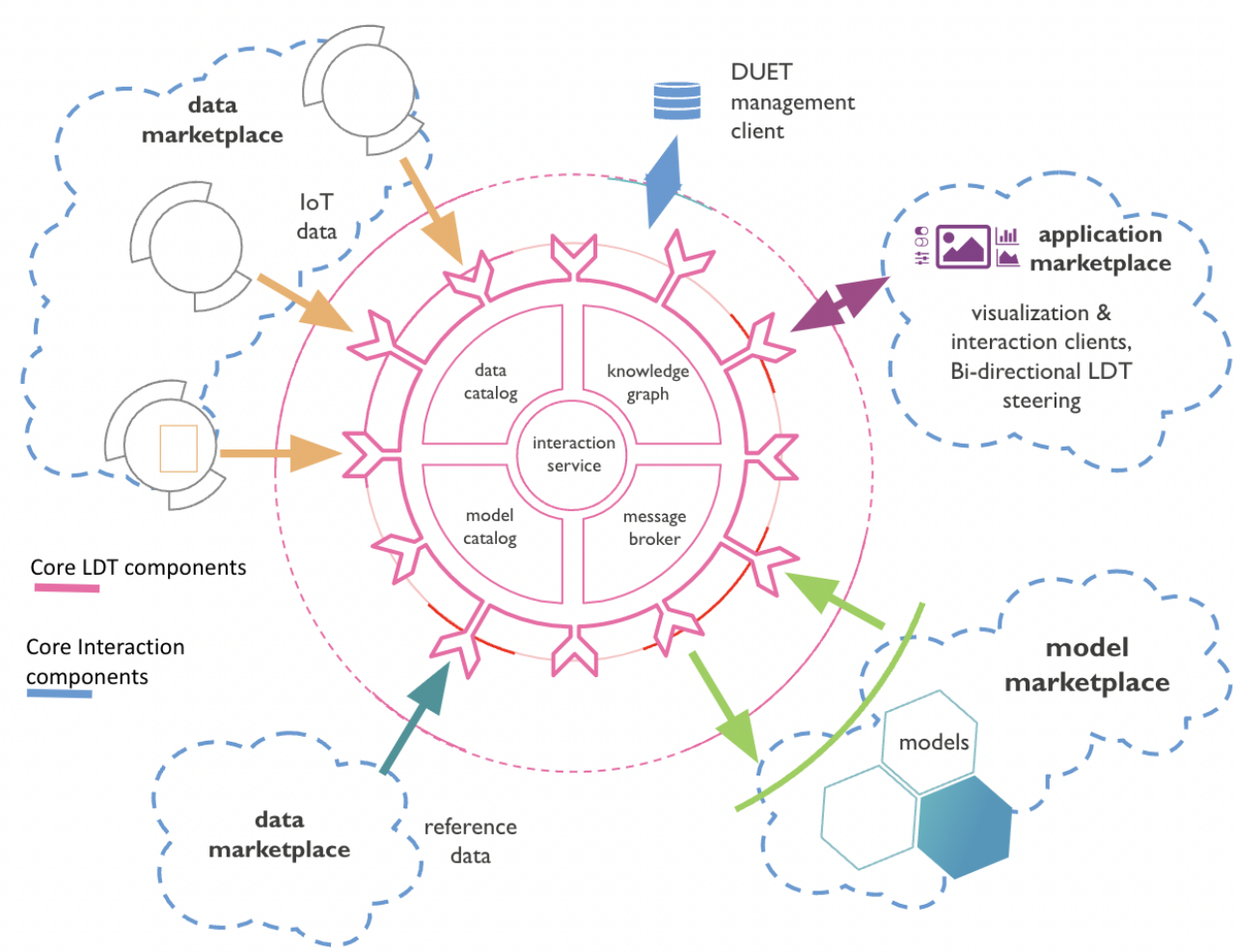

Figure 2: The DUET T-cell - Acting as a data broker connecting the data sources to the different DUET components

4.2.2. Architectural Principles

The DUET solution combines a number of guiding principles reflected in the overall architecture and approach. The main principle can be described as "decoupling components with different functions to maximise interchangeability". Every component should be replaceable by a different component that fulfils the same role. A clear separation of concerns is required for this. This principle is especially important for the use of data sources and their semantics, simulation models and algorithms and the orchestration between both. During DUET's design phase, the principles were translated into a comprehensive vision and implementation rules:

Avoid integration issues by adopting the principles of data spaces to interconnect the source data platforms by:

- Publishing data according to open standards (especially semantics)
- Converging on a common smart city ontology
- Enabling interconnectivity at the data level by using a smart persistent identifier strategy
- Allowing data sets to be published in multiple formats/schema's using a multitude of protocols
- Providing reusable data pipeline components for mapping, transforming, … data streams

- Allowing for both data and model marshalling

Apply smart data principles for establishing simulation algorithmic interoperability, trust and transparency by:

- Managing metadata with specific attention to data quality, data lineage and model descriptions, quality assumptions and assurances
- Formally define case and scenario management and digital twin expert interactions utilising a standard (including a semantic definition) to ensure interoperability at the orchestration level
- Establishing an abstract orchestration specification to enable DUET component interactions

The above architectural principles align very well with the Gemini Principles for Digital Twins defined by CDBB (Bolton et al., 2018), as depicted below.

Figure 3: The CDBB Gemini Principles

Allowing LDTs to be connected in a Web-of-Twins, marketplace or twin-place needs to use the right technology to allow the stakeholders to get the right insights for their purpose and trust these insights. Translating this to the technical architecture, means that it must enable the purpose and trust with effective technical functions, needing distribution/federation, standardisation of connectivity and a clear capacity to adapt with new functions (like the AI models) keeping the trust and purpose objectives intact. The architecture needs to address also the needs of Society 5.0 where resilient and cognition LDTs will restore the balance between information automation and human interpretation and trust.

4.2.3. The role of standards and MIMs

ICT standards are an integral component of the DUET architecture and play an essential role in the ongoing development and wider implementation of DUET. It is important that DUET complies with existing leading open ICT standards, including the MIMs, to make widespread take-up and adoption easier. DUET also has the opportunity to help shape the new standards that will be needed, which will benefit the move towards LDTs more generally and open up new opportunities for take-up of the DUET solution. The opportunity to help shape International Standards, see section 4.2, will also help open up opportunities for European companies globally.

DUET relies on existing MIMs such as MIM1 Context Information Management, MIM2 Data Models and MIM3 Data Ecosystem Management. It is feeding into some of the MIMs that are in the process of being developed, especially to MIM7 Geospatial, but also to MIM6 Security, MIM9 Analytics and MIM10 Resource Management. MIM4 on Personal Data Management and MIM5 on Fair AI are also relevant.

DUET also implies/suggests a new MIM, namely Abstract Orchestration for the facilitation of orchestrating federated components in a data pipeline as described in DUET Deliverable 3.9 (Michiels & Vervaet, 2021). This suggestion is based on the concrete need for Digital Twin scenario management in all DUET pilot cases materialized by orchestrated and federated components.

Currently, DUET made use of the following existing standards:

Standard Name/abbr.	Description and role in DUET	Standardisation Organisation	DUET component use
DCAT	The Data Catalog Vocabulary is a W3C standard for describing datasets and data services in a catalogue. Within the Public Section Information domain, a European profile DCAT-AP is used to harmonise the descriptions to realise a network of (Open) Data portals throughout Europe. In DUET, DCAT is used as the vocabulary to describe the catalogue of datasets and data services the Digital Twin has access to or provides.	W3C, EC	Data Catalog
CityGML	Standard for exchanging city models. All city models of pilots are based on CityGml, to be visualised in the viewing component.	OGC	Viewing component
GeoJSON	GeoJSON is a format for encoding a variety of geographic data structures	IETF - RFC 7946	Viewing component
3D Tiles	3D Tiles is designed for streaming and rendering massive 3D geospatial content such as Photogrammetry, 3D Buildings, BIM/CAD, Instanced Features, and Point Clouds. It defines a hierarchical data structure and a set of tile formats which deliver renderable content. 3D Tiles does not define explicit rules	OGC	Viewing component

	for visualization of the content; a client may visualize 3D Tiles data however it sees fit.		
WMS	The OpenGIS® Web Map Service Interface Standard (WMS) provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases.	OGC	Viewing component
WMTS	WMTS complements earlier efforts to develop services for the web-based distribution of cartographic maps.	OGC	Viewing component
TMS	A Tile Map Service (TMS) provides access to cartographic maps of geo-referenced data, not direct access to the data itself.	OSGEo	Viewing component
WFS	This International Standard specifies discovery operations, query operations, locking operations, transaction operations and operations to manage stored, parameterized query expressions on vector features.	OGC	Viewing component
Vector tiles	Vector Tiles are packets of geographic data, packaged into pre-defined roughly-square shaped "tiles" for transfer over the web.	Mapbox	Viewing component

Table 2: DUET Overview of used ICT standards overview

4.2.4. The role of interoperable data

It makes sense to describe a standardised process for developing smart city standards that can be used in LDTs. Having a common vocabulary will help a great deal in building the LDT. The International standards-based OSLO framework offers these vocabularies and is used in DUET Deliverable 3.6 (Van Nuffelen & Van Lancker, 2021).

4.3. DUET components TRL level

Overview of the DUET components in DUET, the expected TRL level at the end of DUET and the component ownership.

The table below provides an overview of the components that are part of the T-Cell core Local Digital Twin solution.

Name	description	DUET TRL	Component owner
Interaction Service	Orchestrates the different components involved when running experiments.	TRL 6	IMEC
Knowledge Graph	Presents an ontological model that allows asset discovery in the DUET environment.	TRL 2	IMEC

Data Catalog	Allows to manage and publish data sources for use in DUET. Stores metadata in DCAT format.	TRL 6	IMEC, ATC
Model Catalog	Allows to manage and publish models for use in DUET. Captures all relevant details of models in relation to inputs and outputs.	TRL 2	IMEC,ATC
Message Broker	Intervenes between the registered models and other external systems like visualizations, controlling the data flow from/to them and the Message Streaming Platform.	TRL7	ATC
Management component	It is responsible for the initialisation of the DUET cell and the management of key entities of the system like users, roles and access rights.	TRL7	ATC
Subscription API Service	Allows a user/client of the system, e.g., a model, to subscribe to specific events/data sources of the platform, e.g., the results of another model, to receive the relevant messages through the Message Broker.	TRL7	ATC

Table 3: DUET Core components and TRL levels overview

The second table gives an overview of components that are part of the DUET development that are not part of the DUET T-Cell core.

Name	description	DUET TRL	Component owner
CESIUM JS	Framework for 3D visualization on the web.	TRL9	VCS
IoT Data Connector	Provides a uniform way of connecting to IoT data for other DT components.	TRL6	IMEC
GLayer	Allows exploratory analysis of big Spatio-temporal data relying on GPU accelerated database engine focused on fast data aggregation, filtering and visualisation	TRL9	P4All/ InnoConnect
VC Map API	Framework for 3D & 2D visualization on the web, based on CESIUM JS and OpenLayers JS.	TRL8	VCS
OpenLayers JS	high-performance, feature-packed library for 2D visualizations.	TRL9	VCS
Viewing component as a plugin for VC Map	Plugin developed within DUET project for displaying 2D / 3D data in web, based on VC Map API	TRL4	VCS
Dashboards	Interactive dashboards visualising and contextualising IoT sensor data, map and graph functionalities	TRL7	ATC

Table 4: DUET Additional components and TRL levels overview

4.4. Models/components overview related to the pilots

The table below gives an overview of the applied simulation models in DUET.

Component Name	TRL	Owner	Athens	Flanders	Pilsen
Traffic Modeller: Calculates traffic density in the city for each day/hour. It also allows to recalculate traffic density based on added events or changes in the road network.	9	P4ALL	Yes		Yes
Noise modeller: Calculates noise caused by traffic in the city. Recalculates the noise on-demand (typically by changed traffic situation)	7	P4ALL			Yes
Air quality model: Calculates air concentration levels of several agents (NOx, NO2, PM10, PM2.5, EC…). Traffic emissions are calculated, and their dispersion is combined with other (background) emission sources. The model relies heavily on parallel GPUs and HPC for acceptable calculation times.	8/9	TNO	Yes	Yes	Yes
Noise model: Calculates Noise levels caused by traffic in Lden (Level weighted for Day, Evening, and Night). Noise emissions of traffic are 'raytraced' towards calculation points. The model relies on parallel computing (GPU & HPC) to achieve acceptable performance.	8/9	TNO	Yes	Yes	(Yes)
Traffic Model: Integrated traffic model of the Flanders region and the city of Gent based on traffic densities and origin/destination matrixes implemented via KUL open source software components in cooperation with P4ALL		Gent/ AWV		Yes	
Air quality model: Fast calculation of yearly averages of PM10, PM2.5 fine dust particles based on emissions by traffic and spatial elements like elements and spatial morphology.	9	VITO		Yes	
Air quality model: Fast calculation of yearly averages of NO2 emissions by traffic and spatial elements and spatial morphology.	9	VITO		Yes	

Table 5: DUET Simulation models and TRL level overview

5. Further development of DUET

The future developments chapter describes the need to extend the functionalities of existing components, the need for new components, and the need for internationally recognized IT standards. The future development of DUET is also closely linked with EU strategies related to AI, HPC and data spaces on the one hand and the EU societal policies like the green deal, climate-neutral cities and the EU democracy and societal policy on the other hand.

5.1. Functionalities

Below you will find a list of functionalities that are part of the core of a future, fully scalable and open Local Digital Twin solution.

5.1.1. Extended data and service catalogue

DUET has integrated a service, data and model catalogue, providing the necessary tools and settings for an immediate application of the available catalogue items into the Local Digital Twin itself. The seamless integration between the catalogue and the DUET map viewer is very powerful. The next step is to store the metadata in the catalogue using DCAT, ISO19115 and Inspire specifications, extended with additional information to allow direct use in the Local Digital Twin. This last element can be part of an international standardisation process with W3C or ISO.

5.1.2. Extended model catalogue

DUET already integrates simulation models and data services in an integrated catalogue yet require further research. To meet the requirements of model cooperation without the necessity that models know each other's formal definitions, standards for model signature and model calls will be needed.
Models demand more than data services specific information about their use and application possibilities. Compared to a data catalogue, which is already well known, a model catalogue is relatively new.

5.1.3. Model and data marketplace

Allowing 3rd parties to advertise and integrate their datasets, data services, and simulation model services demands extended data and services management. Providing trust (security, reliability) to suppliers and users dealing with different storage and application connections and facilities are some of the key elements.

5.1.4. Integration of data spaces

LDTs are especially valuable in situations that require cross-domain decision support. The cross-domain aspect entails that the required data will need to be sourced from a variety of data sources, from a multitude of organisations. Ideally, a Local Digital Twin doesn't store the data but derives data from additional sources to keep the solution scalable and use federated data storage solutions. Data space architectures such as IDSA (IDSA, 2020) and federated service specifications defined by Gaia-X support the Local Digital Twin philosophy and can, when deployed, provide solid foundations for building LDTs.

IDSA (International Data Spaces)

The connector/receptor concept of the DUET T-Cell architecture resembles the connector-paradigm of the IDSA, and by further converging with IDSA, DUET core components will become more portable. This will enable the LDT infrastructure to benefit directly from the investments made in Data Space technology at the European Level.

Every component of DUET today can be mapped onto the IDS-RAM architecture. A more strict separation of concerns between the DUET components will make them more compliant, portable, interchangeable and versatile. Fitting the components onto the IDS-RAM architecture and aligning them is a good starting point.

Gaia-X

Better alignment of the different core services of DUET with the federation services of Gaia-X (Gaia-X, 2022) will drive adoption (Gaia-X, 2021). In order of priority, the following concerns proposed by Gaia-X need to be aligned with DUET core services:

- **Federated Catalogue**: DUET asset catalogue (data catalogue, model catalogue, …)
- **Identity and Trust**: the identity and access management (IAM) system of DUET
- **Data sovereignty**: federated data processing and analysis through model interoperability, portability and orchestration
- **Compliance**: ensuring data lineage, verifiability, licensing and conformance in the DUET marketplace

5.1.5. Extended model and data interaction

Data-driven policies rely on evidence, provided by applying models to data to understand and assess the impact of proposed policies before they are used in practice. To structure such exercises, a formal data model is required to capture what problem is being studied, what different scenarios are evaluated, and what data and models are needed to analyse the different scenarios and compare their outcomes.

Capturing this information is done by the scenario manager. Specifically, it captures:

- Case level data such as the problem being evaluated, the context and more details
- Scenario level data that contain specific proposed solutions, including a clear name and a description, but also:
    - Input data sources used for the analysis (references to the data catalogue)
    - Computational models/algorithms used for performing the analysis (references to the model catalogue)
    - Output data sources that capture and store the outcome of the analysis
    - A description of how the models and data sources are interconnected (i.e., a formal orchestration description)

This information model covers "**call semantics**", by which we mean that this describes what models are in play and how inputs and outputs interconnect them. To validate that input and output data sources are compatible with the models applied to them, there is also a need for a formal definition of **model signatures** (cf. section 4.2.2 and DUET Deliverable 3.9 (Michiels & Vervaet, 2021)).

Model location	Data location

Model runs on external servers	Data is used from external sources (data spaces)
Model runs on the Digital Twin infrastructure	Data is on the Digital Twin itself

Table 6: DUET Simulation Model and Data location options

5.1.6. Extended system management

A scalable Local Digital Twin as a service (LDTAAS) ideally allows every city, and local communities in the future to set up their minimal Local Digital Twin based on available datasets and simulation models, to get at least an overview of the available smart-city relevant data like in-situ sensors.
Based on the experience of running three LDTs on one platform, the current DUET system management already discriminates between the three pilots and between each single-pilot case level (e.g. a simulation of the effect of a road closure).

5.2. ICT Standards

Open ICT standards are key for an open Local Digital Twin solution and ensure long term modularity of the T-Cell architecture itself and its cooperation with data spaces, IoT data services, simulation models and visualisation clients.

5.2.1. Need for new standards

LDTs are complex integrative systems with a demand for new or impactful re-design of existing standards based on specific Local Digital Twin related requirements. Especially standards allowing more structured and advanced interaction between components are central.

Digital Twin interactions
LDTs can support different types of interactions:

- They can be connected to the real world and respond by using (near) real-time data to predict future events using simulation models that allow them or their operators to take appropriate action.
- In the context of what-if scenarios, they may respond to a Local Digital Twin operator's actions that are applying changes in a virtual environment, e.g., closing an area for city traffic or designing a low-speed zone to test the impact of such an action on the city environment in advance. In particular, the following aspects can be modelled in DUET:
    - Changes in traffic density by recalculation a traffic model in the area
    - Changes in air pollution produced by traffic
    - Changes in noise levels produced by traffic
- LDTs should also support a scenario independent triggering of each model/algorithm that runs on-demand when an operator explicitly requests it

This type of capabilities calls for a clear definition of **interaction event streams** since these are mechanisms that span multiple digital twin components that we envision to be interchangeable.

Model Signature

In the same way that DCAT specifies metadata for data sources, we need a metadata model for models that specify:

1. What assumptions do models make about input data
2. The format and schema of the input data sources
3. The supported delivery method(s) (i.e., technical interfaces) of the input sources
4. The properties, format and schema of the output data sources
5. The supported technical interfaces for the output data source
6. Quality assurances provided by the model

This will help ensure that models are sensibly applied to data streams with a meaningful outcome.

Case and Scenario Management

Essential to the concept of LDTs is the ability to run experiments including many different data sources, spanning multiple domains, and using a combination of simulation models and algorithms that materialise in a data processing pipeline. This calls for a shared information model of case and scenario management[2] that builds upon the definition of model signature (see above) and that allows domain experts to construct such a data pipeline in the context of a scenario.

This information model should describe a data processing pipeline in a rich but technology-agnostic manner so that there is no technology lock-in for the digital twin.

Lineage Metadata

Understanding where data comes from is essential for establishing trust. This trust is needed to ensure that the results of simulation models are sufficiently reliable to serve as a foundation for policymaking. The Case and Scenario Management information model explicitly specifies how the results of experiments were created and can thus be used to state their lineage. In turn, the data sources should do the same so that the full lineage of the data becomes apparent.

Model Management & Model orchestration

The resulting information models from Model Signature and Case and Scenario Management can be used to establish the orchestration of the interactions and the models involved in a scenario. This could be a new MIM. Such orchestration can be handled by existing solutions such as Apache Airflow or Apache NiFi. The lineage aspect should be included in such a MIM to highlight the importance of trust.

Local Digital Twin International Standards

At this present time, key international Standards Development Organisations such as ISO, IEC, JTC1 and ITU are exploring a Joint Working Group on LDTs. The role will be to identify standards gaps and help pull together a coordinated effort to develop the standards needed. The Smart & Sustainable Cities and Communities Sector Forum of CEN/CENELEC/ETSI is setting up a Local Digital Twin Task Group that will investigate the requirements for European standards. DUET will be able to feed directly into both these processes through OASC.

5.2.2. Interaction with MIMs

Relation between the DUET Digital Twin and the OASC MIMs - see chapter 3.2.3.

[2] A case can be seen as a problem definition, and scenarios are propositions for solving such a problem of which the (simulation) outcomes are to be compared.

The DUET lessons learned feed into the ongoing development and testing of the MIMs, and this will be further tailored in the future to support the requirements of LDTs across Europe.

6. Conclusions

The DUET consortium offers today a **unique scalable and open Digital Twin Architecture that functions** well as proof of concept and is able to cooperate with a variety of external systems of different maturity levels. Today, DUET core integrates slow- and fast-moving data and a simulation model catalogue that supports multi-domain simulation modelling, usable for policy prediction and more. DUET also offers scenario comparison and analysis tools to outreach to citizens and community groups to co-create and co-decide.

This state-of-the-art document describes DUET as it is today but also what an Open DUET-based, more mature solution could look like in the future. More specifically, this document aims to contribute to supporting and achieving the following objectives:

- Providing an overview of the current components and TRL levels to depict the fit-gap towards a TRL 7 (system prototype demonstrated in operational environment) or TRL 8 (system complete and qualified) solution.
- Contributing to a qualified Local Digital Twin (LDT) solution based on open standards, open architecture principles and minimal interoperability mechanisms to avoid vendor lock-in.
- Identifying remaining evidence-based and policy informed smart-city related decisions by creating a network of cooperating simulation models as part of an LDT. Central is a strategy for data processing, model interoperability and orchestration.
- Integrating policy outcomes from an LDT into the public debate and decision-making process by using storytelling techniques, scenario presentations, and discussions that contribute to a higher level of public awareness and understanding.

This state-of-the-art document will also address the need for trust, transparency and cooperation inside organisations to overcome silo-thinking between organisations, to set up collaborations on complex policy questions and challenges, and by extension to all the players in the quadruple helix involved in realising policy goals and outcomes. An LDT is successful when it contributes to these human interaction-related challenges. The technical integration based on an LDT as a system of system is one of the most promising ways to realise LDTs, step by step.

7. References

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