Alliance for AI, IoT and Edge Continuum Innovation

WG Standardisation
Focus Group High Level Architecture

BDV BIG DATA VALUE ASSOCIATION

BDVA Task force Data space, Task force Standards and benchmarking

standICT.eu2026
ICT Standardisation Observatory and Support Facility in Europe

TWG – Digital Twins

HSbooster.eu
Horizon Standardisation Booster

Guidance for the Integration of Digital Twins in Data Spaces

Release 1.0

30 August 2024

Legal notice

The document has been prepared for the Europen Commission and SDOs however it reflects the views only of the authors, and neither the European Commission nor the Standards Developing Organisations can be held responsible for any use which may be made of the information contained therein. More information on the European Union is available on the internet (http://europa.eu).

About StandICT.eu

The StandICT.eu 2026 Coordination and Support Action project is funded by the European Union under grant agreement no. 101091933. The project is coordinated by Trust-IT Srl (IT) in quality of Technical Coordinator and Dublin City University (IE) in quality of Financial Coordinator, supported by the partners European Digital SME Alliance (BE), OpenForum Europe (BE), Australo (ES) and Fraunhofer ISI (DE). The content of the present report does not represent the opinion of the European Union, and the European Union is not responsible for any use that might be made of such content.

Executive Summary

This document focuses on the integration of digital twins in data spaces:

- it provides a context on data spaces, digital twins, IoT and edge computing and standardisation:
- it provides an analysis on the integration of digital twins in data spaces taking an architecture approach;
- it describes a large number of digital twin use cases in domains such as agriculture, connected vehicles, smart cities, energy, smart manufacturing;

The document can be used to provide insights and sources for future standardisation work related to the integration of digital twins in data spaces.

This document also leverages the following reports:

- The EU Observatory for ICT Standardisation (EUOS) published in June 2022 a report prepared by the StandICT task work group (TWG) entitled Landscape of Digital Twins[1].
- AIOTI published in September 2022 a report prepared by the standardisation working group (WG) entitled Guidance for the Integration of IoT and Edge Computing in Data Spaces[2].
- BDVA published in February 2024 a report prepared by the task force on data spaces and task force on standards entitled Data Sharing Spaces and Interoperability[3].

1 https://zenodo.org/records/6556917
2 https://aioti.eu/wp-content/uploads/2022/09/AIOTI-Guidance-for-IoT-Integration-in-Data-Spaces-Final.pdf
3 https://bdva.eu/news/bdvas-position-paper-on-data-sharing-spaces-and-interoperability/

Table of Contents

Table of figures

Table of tables

1. Context

1.1 Data Spaces

The following excerpts from the AIOTI report on the integration of IoT and Edge computing in data spaces[1] provides a good introduction on data spaces:

> *While the term **data space** was coined more that 10 years ago[2], it was not until recent years that a number of position papers such as BDVA[3] [4] OpenDei[5], and initiatives, such as IDSA[6], or GAIA-X[7] [8] or FIWARE[9] have started to propose a common understanding.*

OpenDei provides a comprehensive definition:

> *From a technical perspective, a **data space** can be seen as a data integration concept which does not require common database schemas and physical data integration, but is rather based on distributed data stores and integration on an "as needed" basis on a semantic level. Abstracted from this technical definition, a data space can be defined as a federated data ecosystem within a certain application domain and based on shared policies and rules*

FIWARE provides a definition which is aligned:

> *A **data space** can be defined as a decentralized data ecosystem built around commonly agreed building blocks enabling an effective and trusted sharing of data among participants.*

1 https://aioti.eu/wp-content/uploads/2022/09/AIOTI-Guidance-for-IoT-Integration-in-Data-Spaces-Final.pdf
2 https://en.wikipedia.org/wiki/Dataspaces
3 Towards a European-Governed Data Sharing Space. Enabling data exchange and unlocking AI potential. April 2019 https://bdva.eu/sites/default/files/BDVA%20DataSharingSpace%20PositionPaper_April2019_V1.pdf
4 Towards a European-Governed Data Sharing Space. Enabling data exchange and unlocking AI potential. November 2020 https://www.bdva.eu/sites/default/files/BDVA%20DataSharingSpaces%20PositionPaper%20V2_2020_Final.pdf
5 https://design-principles-for-data-spaces.org/
6 https://www.internationaldataspaces.org/wp-content/uploads/2019/03/IDS-Reference-Architecture-Model-3.0.pdf
7 https://www.data-infrastructure.eu/GAIAX/Redaktion/EN/Publications/gaia-x-technical-architecture.pdf? blob=publicationFile&v=5. Release-June 2020
8 https://www.data-infrastructure.eu/GAIAX/Redaktion/EN/Publications/gaia-x-technical-architecture.pdf
9 https://www.fiware.org/marketing-material/fiware-for-data-spaces -(release June 2021)

The following table shows some of the initiatives on data spaces.

Table 1 – Data space initiatives

EU Common European Data Space **Strategic Initiative**	https://digital-strategy.ec.europa.eu/en/policies/data-spaces The Common European Data Spaces will help unleash the enormous potential of data- driven innovation. They will allow data from across the EU to be made available and exchanged in a trustworthy and secure manner. EU Businesses, public administrations, and individuals will control the data they generate. At the same time, these data holders will benefit from a safe and reliable framework to share their data for innovation purposes. Common European Data Spaces will enhance the development of new data-driven products and services in the EU, forming the core tissue of an interconnected and competitive European data economy. A working document (February 2024) is available here: https://digital-strategy.ec.europa.eu/en/library/second-staff-working-document-data-spaces The following domains are covered: agriculture, cultural heritage, energy, finance, green dal, health, language, manufacturing, media, public administration, research and innovation, skills, tourism
IDSA	https://internationaldataspaces.org/
International data space association	IDSA is an association with the following mission: create a digital future in which all players can realize the full value of their data through equal access to secure and sovereign data sharing among trusted partners. Mission and vision: "It is time to change the way data is shared. We want to pave the way for a data economy in which every company and every person keeps full control over their data treasures. We believe in a data economy in which you do not rely on a solution that is owned by one big player. This is why we create the required standards for data spaces which grant data sovereignty to all participants to share data without regret" Data sovereignty: "IDSA aims to enable people, organizations, and governments to have control over their data, including collecting, storing, sharing, and use. This means making rules for data sharing and use, like data policies and contracts, with varying levels of control. We call this data sovereignty. IDSA offers guidelines and a framework for ensuring data sovereignty in data spaces". Data Spaces: "Our vision depends on data spaces – which comprise relationships between trusted partners that are governed by IDSA standards for secure and sovereign data sharing, certification and governance for business and industry across Europe and around the world"

Gaia-X	https://gaia-x.eu/ The Gaia-X European Association for Data and Cloud AISBL represents the core of the organisational structure. It is an international non-profit association under Belgian law (French: association internationale sans but lucratif, shortened to AISBL). It was founded to develop the technical framework and operate the Gaia-X Federation services. Officially, the Association was founded by 22 companies and organisations in January 2021. Until today, over 300 members have joined and more are welcome. Its members are committed to upholding the values of data protection, transparency, openness, security, and respect for data rights. They are either companies with a provider or user background of data infrastructures, IT-start-ups, research institutions or business associations. The Association has no business interest of its own. It will develop federation cloud services within the existing cloud infrastructures. To achieve this and to ensure an open and transparent character the Association facilitates the development of an open software infrastructure.
DSSC Horizon Europe project **Data space support etnre** **Started in October 2022** **Expected completion: May 2025**	https://dssc.eu/ The "Data Spaces for Europe" project will set up and operate a Data Spaces Support Centre, as described in the Digital Europe Programme, to operationalize the European Strategy for Data. This Support Centre will facilitate common data spaces that collectively create an interoperable data sharing environment, to enable data reuse within and across sectors, fully respecting EU values, and contributing to the European economy and society. The project brings together associations and industry players, including SMEs, regulators, and digital innovation hubs, to foster the creation of data spaces. The project consortium includes the leading associations and knowledge centres in the domain of data spaces, with a broad membership, an extensive network, national hubs, open-source communities, and data space pioneers. The Support Centre explores the needs of the data spaces initiatives, the common requirements, and best practises. The Support Centre delivers the Data Spaces Blueprint, composed of common building blocks encompassing the business, legal, operational, technical and societal aspects of data spaces. The Blueprint continuously evolves with a user-centric approach, as the result of co-creation with the stakeholders. The existing and emerging data space initiatives and the potential implementers of the building blocks from the Community of Practice in the field of data sharing and they create and adopt the Blueprint and its building blocks. The Support Centre drives adoption through support activities, a platform and web portal for knowledge and asset sharing, help desk, toolboxes, and active engagement with all stakeholders. The project supports the Data Innovation Board in proposing guidelines for common European data spaces. The Support Centre will closely engage with the Data Innovation Board so that the Board can adopt elements in its guidelines, such as cross-sectoral data sharing standards, requirements for security and access procedures.
Simpl **Cloud-to-edge federations empowering EU data space**	https://digital-strategy.ec.europa.eu/en/policies/simpl Simpl is an open source, smart and secure middleware platform that supports data access and interoperability among European data spaces. Simpl plays a major role in the creation of the Common European Data Spaces. These are data ecosystems where users in the same ecosystem share data in a safe and secure manner. Simpl gives data providers full control over who accesses their data in such data spaces

	It includes 3 products: - Simpl-Open: an open-source software stack that powers data spaces and other cloud-to-edge federation initiatives. - Simpl-Labs: an environment for data spaces to experiment with open-source software and assess their level of interoperability with Simpl. Specifically, sectoral data spaces in their early stages of inception will be able to experiment with the deployment, maintenance, and support of the open-source software stack before deploying it for their own needs. Furthermore, more mature data spaces will be able to use Simpl-Labs to assess their level of interoperability with Simpl- Open. - Simpl-Live: distinct instances of the Simpl-Open software stack deployed for specific sectoral data spaces where the European Commission itself plays an active role in their management
Int:net Horizon Europe project **Started in May 2022** **Expected completion: April 2025**	https://www.intnet.eu/ Across the EU, organisations are preparing for the crucial transition to green and sustainable energy. However, despite the existing forms of cooperation and interoperability between Member States, corporations, and institutions, this shift still requires a significant amount of interoperability. The EU-funded IntNET project will offer just that, bringing together researchers, policymakers and framework setters to achieve and monitor any changes required in testing procedures. It will also push for improved cooperation between energy services to ensure synchronisation between providers. "Interoperability depends on cooperation of multiple domains. While for the energy sector technical interoperability is quite well established, interoperability of functions and businesses needs more attention. Even when standards are defined and interoperability models agreed, framework setters, product developers and users need to agree on their deployment and make sure that solutions are compatible with definitions. The Interoperability Network for the Energy Transition project (IntNET) establishes an open, cross-domain community bringing together all stakeholders relevant for the European energy sector to jointly work on developing, testing and deploying interoperable energy services. The community will be formally established to exist beyond project lifetime. With a comprehensive, FAIR knowledge platform and a series of attractive events it guides those who deal with the heterogeneous interoperability landscape of energy services. To support ongoing harmonization of energy services, IntNET will institutionalise an assessment methodology and maturity model (IMM). Involving legal and regulatory bodies from the beginning and constant exchange of interoperability initiatives and standardization bodies will build a deep consensus on how European governance and industry can foster interoperability at all levels. Starting from an extraordinary well balanced and connected consortium of researchers, framework setters (e.g. ministry and EU wide associations), standardisation and communication experts, IntNET's community approach guarantees wide outreach. IntNET will establish a framework for interoperability testing in ongoing projects and harmonize test procedures in a network of closely cooperating, self-sustained testing facilities. Energy service solutions based on the novel IMM and tested according to the IntNET certification process will be awarded with a widely known quality seal for interoperable smart grid and energy products (working title: "IntNET approved"")."

1.2 Digital Twins

Quoting the StandICT landscape report on digital twins[10]:

> *Digital Twins represent one of the most novel and promising concepts within the general trend of digital transformation. They are a distinctly 21st century invention. The term is attributed to Prof. Michael Grieves of the University of Michigan in 2002, and the approach was adopted in particular by NASA around 2010. The concept has proved to be very powerful as it has now been universally used in all the domains.*
>
> *As befits such a new approach, the definition of digital twins is not quite stable yet, and standards are only barely emergent. While Wikipedia defines a digital twin as "a virtual representation that serves as the real-time digital counterpart of a physical object or process," various organizations have attempted to add more precision to the definition. The Digital Twin Consortium's definition is "a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity." This is a more operational definition – one that insists on the nature of the link between the two twins – the digital one and the physical one. It has the merit of explaining that a digital twin is not just a simulation model – there are data and/or commands that get sent by one twin to the other.*

Different classes of Digital Twins – Asset oriented and Environmental Digital Twins

In the projects described later we can see a difference in the use of

- **Asset-oriented Digital Twins** focusing on digital twins of a built or manufactured target entity such as a machine or a smart building, versus
- **Environmental Digital Twins** focusing on digital twins of a natural target entity such as the ocean, the weather or land/terrestrial biodiversity.

In many situations there will also be an interesting interaction between these two types of twins – as built entities will be interacting with natural entities in different ways and vice-versa. There is still evidence that different data and model representations are suitable for the representations of these digital twins – with suggested different standards being promoted by different groups such as "AAS – Asset Administration Shell" from the IDTA – Industrial Digital Twin Association for Asset-oriented digital twins, and various SpatioTemporal/Geospatial APIs, services and models from the Geospatial/Spatio-temporal community such as OGC and ISO/TC211 on Geographic Models and services – for SpatioTemporal, Geospatial and Environmental Digital Twins.

We see potential combinations of these also in the context of Smart Cities and Smart Rural areas – where Digital Twins of the built environment and Environmental digital twins of the natural environment (i.e. air quality, water resources, etc.) are interacting. The similarities and differences of these two classes of Digital Twins – and their interactions – and any convergence between these - is a relevant area to study further.

10 https://zenodo.org/records/6556917

1.3 IoT and Edge Computing

As stated in ISO/IEC 30141 Ed1[11]

> *IoT has a broad use in industry and society today and it will continue to develop for many years to come. Various IoT applications and services have adopted IoT techniques to provide capabilities that were not possible a few years ago. IoT is one of the most dynamic and exciting areas of ICT. It involves the connecting of Physical Entities ("things") with IT systems through networks. Foundational to IoT are the electronic devices that interact with the physical world. Sensors collect the information about the physical world, while actuators can act upon Physical Entities.*
>
> *Both sensors and actuators can be in many forms such as thermometers, accelerometers, video cameras, microphones, relays, heaters or industrial equipment for manufacturing or process controlling. Mobile technology, cloud computing, big data and deep analytics (predictive, cognitive, real-time and contextual) play important roles by gathering and processing data to achieve the final result of controlling Physical Entities by providing contextual, real-time and predictive information which has an impact on physical and virtual entities.*

ISO/IEC 23188 further described Edge computing[12]:

> *Edge computing is increasingly used in systems that deal with aspects of the physical world. Edge computing involves the placement of processing and storage near or at the places where those systems interact with the physical world, which is where the "edge" exists. One of the trends in this space is the development of increasingly capable Internet of Things (IoT) devices (sensors and actuators), which generate more data or new types of data. There is significant benefit from moving the processing and storing of this data close to the place where the data is generated.*
>
> *Cloud computing is commonly used in systems that are based on edge computing approaches. This can include the connection of both devices and edge computing nodes to centralized cloud services. However, it is the case that the locations in which cloud computing is performed are increasingly distributed in nature. The cloud services are being implemented in locations that are nearer to the edge in order to support use cases that demand reduced latency or avoiding the need to transmit large volumes of data over networks with limited bandwidth.*

Standardisation

- Standardisation activities on IoT, Edge computing, Digital Twins, Data spaces have followed the following roadmap:
- ISO/IEC JTC 1/SC 41 (IoT and related technologies) was established in 2016. This led to the publication of ISO/IEC 30141 (IoT reference architecture) in 2018, and of ISO/IEC 30164 (Edge computing) in 2020.
- The topic of digital twins was added in 2020 to ISO/IEC JTC 1/SC 41 which was subsequently renamed IoT and digital twins, This led to the publication in 2023 of ISO/IEC 30172 (digital twin use cases) and ISO/IEC 30173 (digital twin concepts and terminology). Other standards are being developed, in particular, ISO/IEC 30188 (digital twin reference architecture) that is planned for 2025

The topic of dataspace was addressed recently by standardisation committees. ISO/IEC JTC 1/SC 38 started at the end of 2023 the development of the ISO/IEC 20151 standard: Dataspace concepts and characteristics[13]. In parallel, ISO/IEC JTC 1/SC 41 started two preliminary work items, one on the integration of IoT and digital twin, the other one on data extraction.

11 Standard freely available (https://standards.iso.org/ittf/PubliclyAvailableStandards/c065695_ISO_IEC_30141_2018(E).zip)
12 https://www.iso.org/obp/ui/en/#iso:std:iso-iec:tr:23188:ed-1:v1:en
13 https://www.iso.org/standard/86589.html

2. Integrating Digital Twin in Data Spaces

2.1 Fundamentals in Digital Twins

We provide an overview of digital twins concepts based on ISO/IEC 30188 (Digital Twin RA). Figure 1 shows the twinning view:

- twins are called digital entity and target entity,
- the digital entity interacts with the target entity, and
- the environment of the target entity is an environment contains observable elements

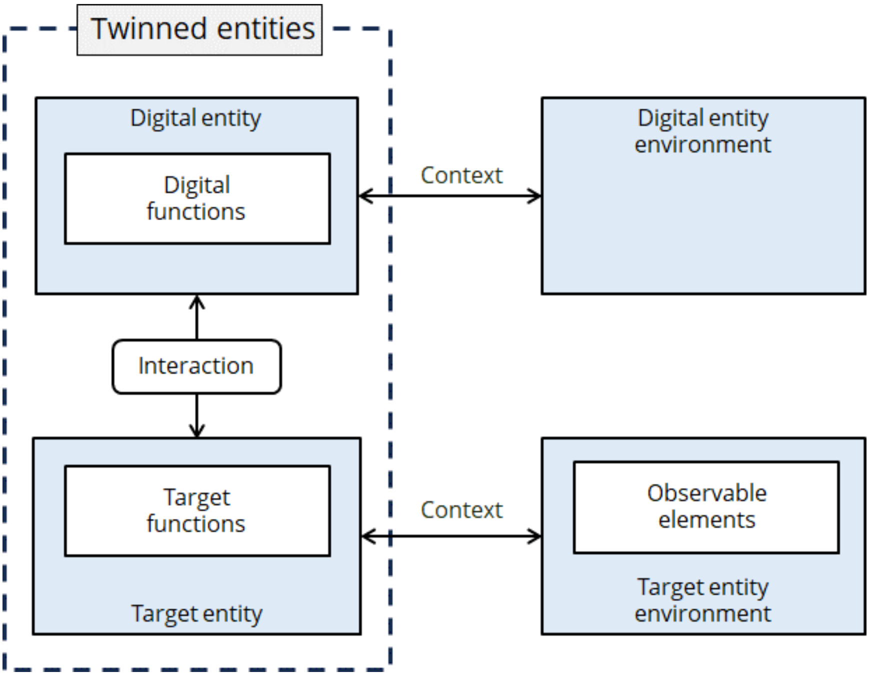


Figure 1 – Twinning view

Figure 2 shows the lifecycle view:

- The twinned entities include each the following processes:
  - Inception,
  - Design,
  - Deployment,
  - Operation and monitoring,
  - Retirement,
  - Verification and development,
- The inception, design, deployment, operation and monitoring, retirement processes of the digital entity can interact with the design, deployment, operation and monitoring, retirement processes of the target entity.

- Both the digital entity and target entity have verification and development processes related to the design, deployment, operation and monitoring processes

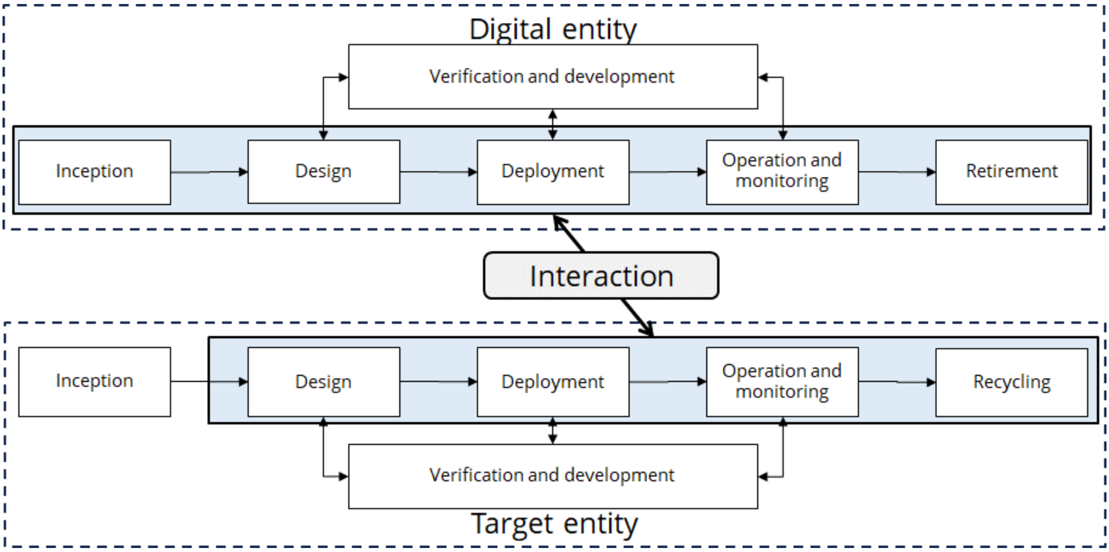


Figure 2 – Lifecycle view

2.2 Functional view

Table 2 lists possible digital twin functions:

- Columns are categories:
  - Define
  - Execute
  - Monitor and measure
  - Analyse
  - Control
- Optimize

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 (the ocean)).

Table 2 – List of potential digital twin functions

	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 implementatio n 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 implementatio n 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 Troubleshootin g Planning	Reduce operating costs Prediction prognosis Sustainability Enhance user experience Reduce carbon emission

	Define	Execute	Monitor and measure	Analyse	Control	Optimize
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 3 lists capabilities according to a scale with four dimensions

- Convergence
- Capability
- Integration, and
- Time

Table 3 – Digital twin potential maturity model

	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

2.3 Business view

Figure 3 shows the business view:

- Services can be provided using either a service-based model or a product based model
- Those services use the digital functions of Table 2

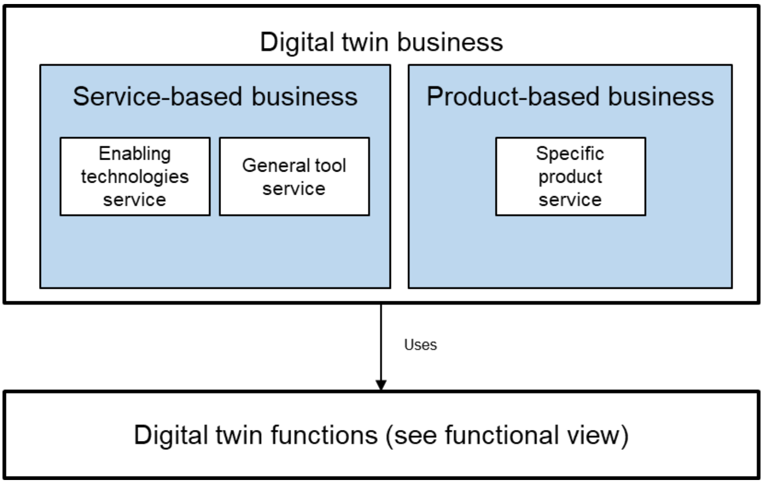


Figure 3 – Business view

2.4 Interoperability view

Figure 4 shows two types of interoperability:

- Inner interoperability between the digital entity and the target entity,
- Outer interoperability between the target entity and its environment.

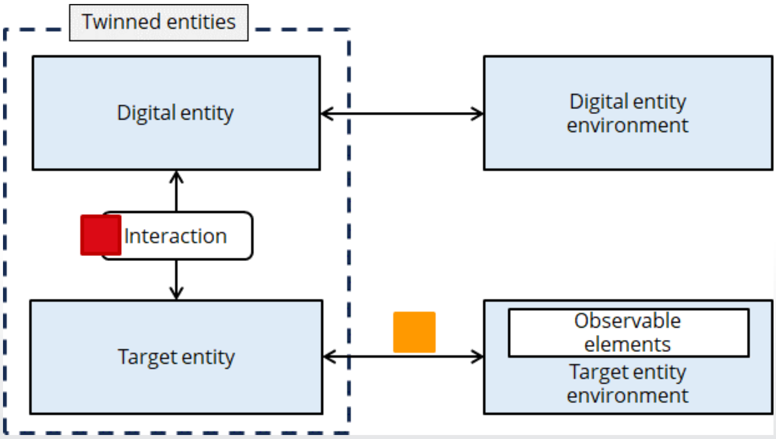


Figure 4 – Inner and outer interoperability

Figure 5 shows a third type of interoperability: the transversal interoperability between digital twins.

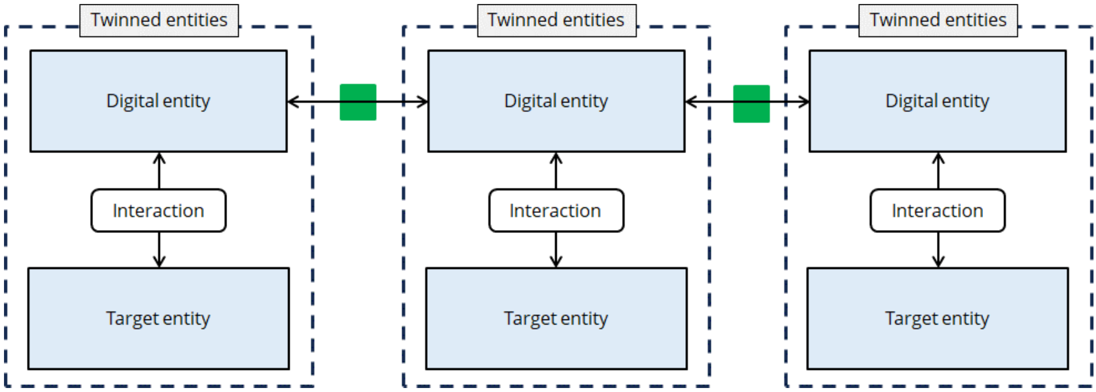


Figure 5 – Transversal interoperability

2.5 Integration of Digital Twins in Data Spaces

2.5.1 Introduction

Figure 6 shows an example of how a digital twin can be integrated:

- The target entity gets data on observable elements (using outer interoperability)
- The digital entity provides data on models associated with the observable elements (using inner interoperability)
- A data fusion process takes place in order to make available information in data spaces (using transversal interoperability)

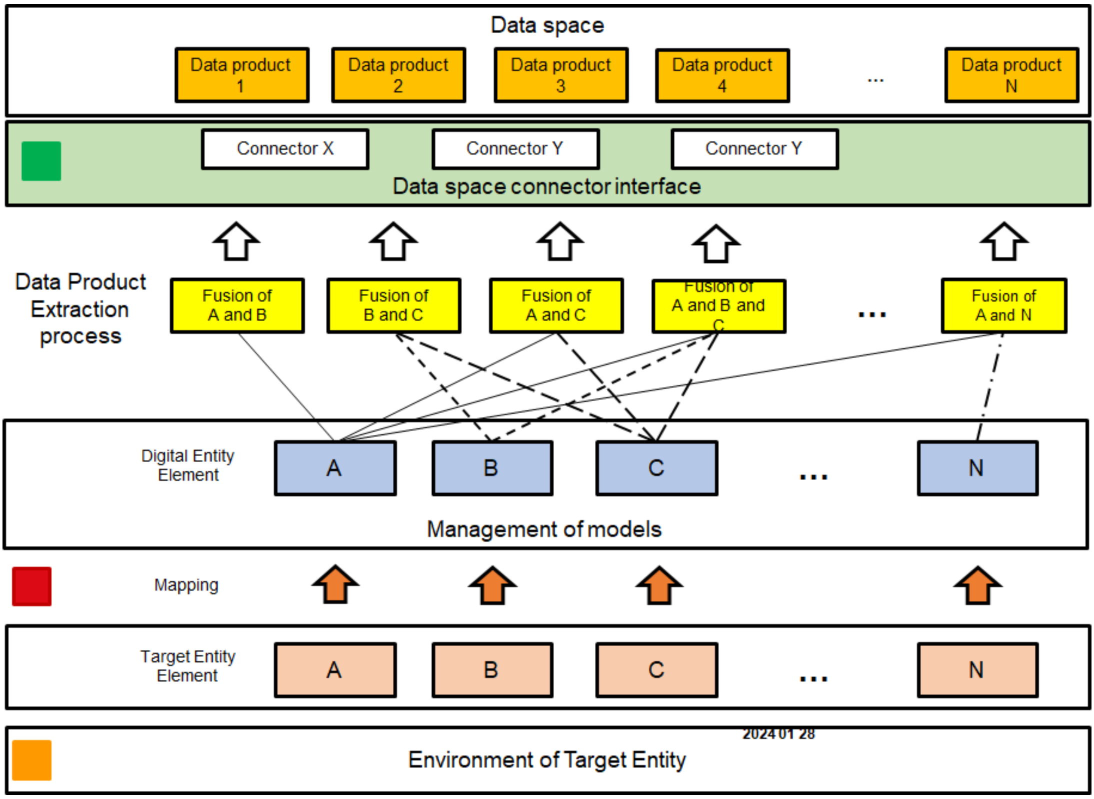


Figure 6 – Connecting digital twins to data spaces

2.5.2 Data architectures patterns

Several data architecture patterns are available. The table below provides examples.

Table 4 – Digital Twin and Data architecture patterns

Data Value architectures from ADRA and BDVA	The following shows a data pipeline (from data acquisition/collection to data preparation to analytics/AI/Machine learning to action, Interaction, visualisation) (related to both the ADRA (AI Data and Robotics Association) framework to the left and to the BDVA (Big Data Value Association) reference model to the right.

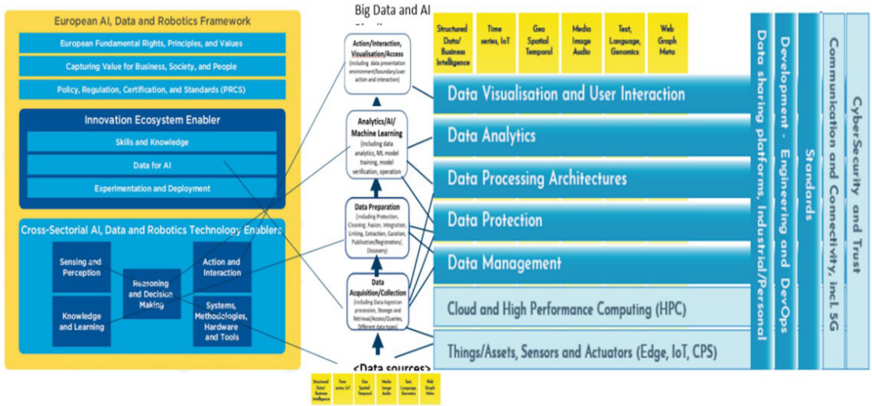


Figure 7 - Data pipeline architecture related to the ADRA and BDVA Reference Models

Figure 8 - The 6 Big Data types of BDVA Reference Model

The above 6 Big Data types that are shown in the BDVA reference model have been identified, based on the fact that they often lead to the use of different techniques and mechanisms and APIs, which should be considered, for instance, for data analytics and data storage: (1) Structured data;

(2) Time series data; (3) Spatio Temporal / Geospatial data; (4) Media, Image, Video and Audio data; (5) Text data, including Natural Language Processing data and Genomics representations; and (6) Graph data, Network/Web data and Metadata. In addition, it is important to support both the syntactical and semantic aspects of data for all Big Data types.

In the context of Digital Twins for various domains, experiences has shown that data representation for all 6 data types will be relevant to support through data representations handled by data spaces and data lakes/data storage.

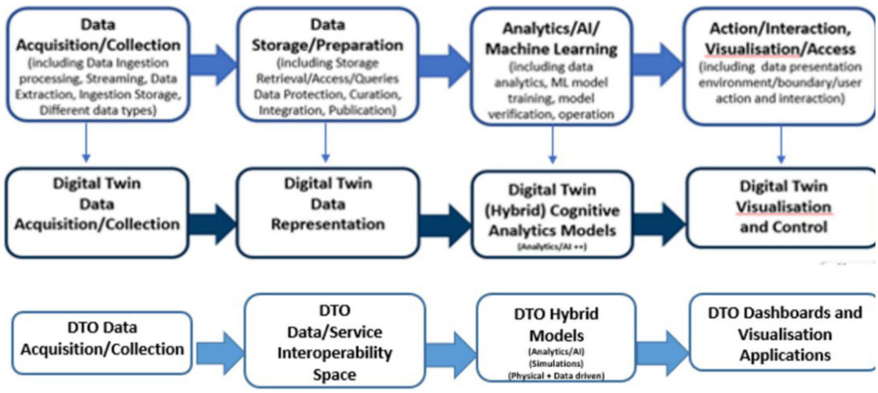


Figure 9 - Data pipeline steps adapted Digital Twin pipelines

The figure above shows the various component and service areas involved in the Digital Twin pipeline steps. It illustrates how the four steps are adapted as the foundation for a specialised four- step pipeline architecture specific to Digital Twins and further adapted for Digital Twins of the Ocean (DTO).

Digital twin pipeline pattern

This pattern describes how the data/control is flowing during operations from the target entity to digital entity

- From
  - data acquisition
  - sensors
  - which type of sensors
  - historical data

  to

  - digital twin data representations (which type of data representation
- From
  - which type of data sources (including access to shared data from data spaces

  to

  - digital twins behavioral models for analytics, predictions, prescriptions
  - control (including actuators and feedback to the target entity),
  - interactive interaction with the twin, and
  - sharing of digital twin data products/results to others through data spaces and APIs.

Further references on the digital twin pipeline description can be found here:

- *Technologies and Applications fornBig Data Value | SpringerLink*
- *Big Data and AI Pipeline Framework: Technology Analysis from a Benchmarking Perspective | SpringerLink*
- *Data-Driven Artificial Intelligence and Predictive Analytics for the Maintenance of Industrial Machinery with Hybrid and Cognitive Digital Twins | SpringerLink*

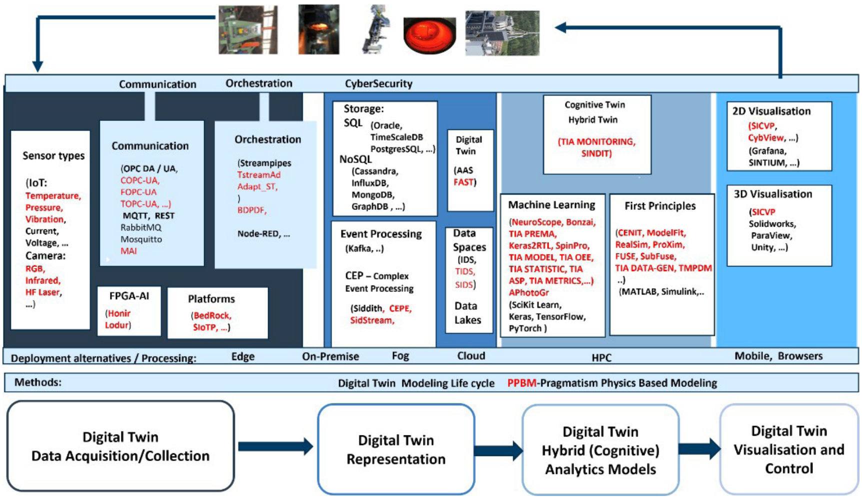


Figure 10 – Capabilities of a digital twin data pipeline

Here is a description of each of the steps in the digital twin data pipeline: Digital Twin - Data Acquisition/Collection

This Digital Twin step maps to *Data acquisition and collection* from various sources, for input to the Digital Twin. This includes both streaming data and data extraction from relevant external data sources and sensors. It includes support for handling all relevant data types and also relevant data protection handling for this step. In the Digital Twin sensor context this includes various data types such as numerical values from sensors, but also images from RGB and Infrared camera sensors, as well as many other types of sensors – typically with much variation between different digital twin domains. This step is often associated with the use of both real-time and batch data collection, and associated streaming and messaging systems. It uses enabling technologies in the area using data from things/assets, sensors and actuators to collect streaming data-in-motion as well as connecting to existing data sources with data-at-rest. Often, this step also includes the use of relevant communication and messaging technologies. This steps maps to *AI Data Acquisition/Collection* by using enablers from Sensing and Perception technologies, which includes methods to access, assess, convert and aggregate signals that represent real-world parameters into processable and communicable data assets that embody perception.

Digital Twin Data Representation

This Digital Twin step maps to *data storage/preparation* by use of appropriate storage systems and data preparation and curation for further data use and processing. Data storage includes the use of data storage and retrieval in different databases systems – both SQL and NoSQL, like key-value, column-based storage, document storage and graph storage and also storage structures such as file systems. Tasks performed in this step also include further data preparation and curation as well as data annotation, publication and presentation of the data in order to be available for discovery, reuse and preservation. Further in this step, there is also interaction with various data platforms and data spaces for broader data management and governance.

This step is also linked to handling associated aspects of data protection. This steps map to *AI Data Storage/Preparation* by using enablers from Knowledge and learning technologies, including data processing technologies, which cover the transformation, cleaning, storage, sharing, modelling, simulation, synthesizing and extracting of insights of all types of data both that gathered through sensing and perception as well as data acquired by other means.

This will handle both training data and operational data. It will further use enablers for Data for AI which handles the availability of the data through data storage through data spaces, platforms and data marketplaces in order to support data driven AI. With a focus on Digital Twin representation there is a question of which representation approaches to take.

Digital Twin Hybrid and Cognitive Analytics Models

This Digital Twin step maps to *Analytics/AI/Machine Learning* that handles data analytics with relevant methods, including descriptive, predictive, and prescriptive analytics and use of AI/Machine Learning methods and algorithms to support decision making and transfer of knowledge. For Machine learning, this step also includes the subtasks for necessary model training and model verification/validation and testing, before actual operation with input data. In this context, the previous step of data storage and preparation will provide data input both for training and validation and test data, as well as operational input data. This step maps to *AI Analytics/AI/Machine Learning*: using enablers from Reasoning and Decision making which is at the heart of Artificial Intelligence. This technology area also provides enablers to address optimisation, search, planning, diagnosis and relies on methods to ensure robustness and trustworthiness. *Digital Twin Hybrid (Cognitive) Analytics* with AI/Machine learning models based on applying and evaluating different AI/machine learning algorithms. This is further extended with first-principles physical models – to form a Hybrid Digital Twin.

Digital Twin - Action/Interaction, Visualisation and Access

This Digital Twin step maps to *Action/Interaction, Visualisation and Access* (including data presentation environment/boundary/user action and interaction) identifies the boundary towards the environment for action/interaction, typically through a visual interface with various data visualisation techniques for human users and through an API or an interaction interface for system boundaries. This is a boundary where interactions occur between machines and objects, between machines, between people and machines and between environments and machines. The action/interaction with the system boundaries can typically also impact the environment to be connected back to the data acquisition/collection step, collecting input from the system boundaries. This step maps to *AI Action/Interaction, Visualisation and Access*: using enablers from Action and Interaction – where Interactions occur between machines and objects, between machines, between people and machines and between environments and machines. This interaction can take place both through human user interfaces as well as through various APIs and system access and interaction mechanisms. The action/interaction with the system boundaries can typically also be connected back to the data acquisition/collection step, collecting input from the system boundaries.

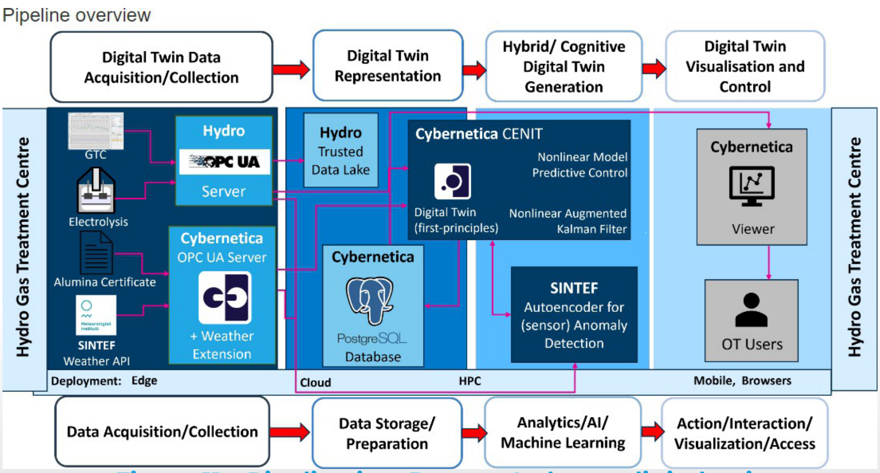
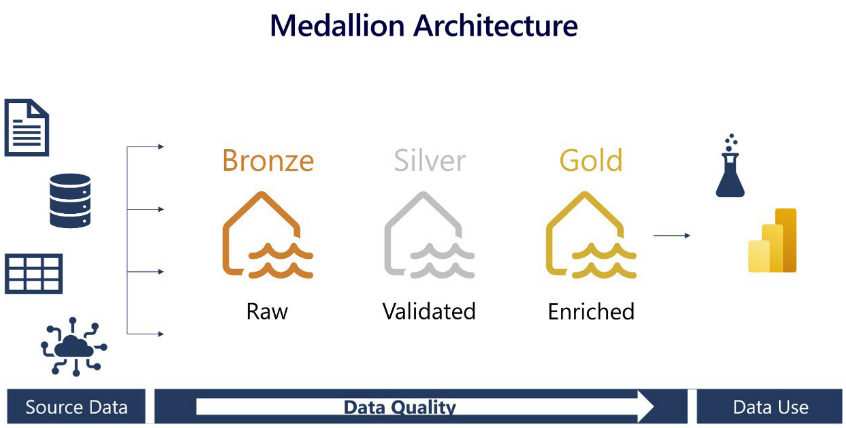


Figure 11 – Pipeline in a Process Industry digital twin

	In the COGNITWIN project (cognitwin.eu) the Digital Twin pipeline has been applied to 6 different digital twins for different process industries.
Data lake medallion architecture	This pattern shows how one can transform data from raw data to validated data to enriched data or (ARCO – Analysis Ready/Cloud Optimised) data  **Figure 12 – Data Lake Medallion architecture pattern** The initial focus of Data Lakes has been on storage of raw data. The Medallion Architecture has introduced the data lake medallion levels from Bronze to Silver to Gold data. It uses the term Data Lake also for enhanced and validated data. In some of the current Digital Twin architectures a Data Lake is a core components for the representation of the data of a digital twin, but it is then emphasised that this is ARCO data (Analysis Read Cloud Optimised) – i.e. Data Lake Gold level according to the Medallion Data Lake architecture. The bronze data lake will be the first step for the collection of various sensor raw data which typically will be validated, enhanced and harmonised (silver) before being t contextualised and enriched as target data for analytics and AI processing (gold).

3. Digital Twins Projects

3.1 Description Template

This template is proposed so that projects can provide insight on digital twins integration needs.

Table 5 – Digital twin project description template

<Project name>	
Contact	Provide a contact point
Abbreviations	List abbreviations used in your contribution
Description	Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?
Digital twins	Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)
Digital twin functions	Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions? Table 2 describes maturity dimensions. Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?
Interoperability	Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?
IoT and edge infrastructure	Can you describe the IoT and edge infrastructure that your digital twins would like to use?
Data space infrastructure	Can you describe the data space infrastructure that your digital twins would like to use?
Security and privacy	Can you describe security and privacy capabilities that your digital twin would like to use?
Other aspects	Are there other aspects that you would like to report?
References	Provide references (e.g. URL)

3.2 Agriculture Digital Twin – SPADE

Table 6 – Agriculture digital twin – SPADE

SPADE: Multi-purpose physical-cyber agri-forest drones ecosystem for governance and environmental observation	
Contact	Tagarakis Aris, CERTH (a.tagarakis@certh.gr)
Abbreviations	List abbreviations used in your contribution - UAS Unmanned Aircraft System - UAV Unmanned Aerial Vehicle
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** The objective of SPADE is to develop an ecosystem leveraging the use of UAVs to provide digital services in agriculture. Covered applications involve crop production, forestry, and livestock: - A crop production use case in Spain. Applications include crop monitoring with a drone swarm, cooperative (including tethered) drones for crop/orchard monitoring, large drone for crop operations (spraying) - A forestry use case in Norway. Applications include a drone swarm for forest inventory, a tethered drone for operational support of a wheeled forest harvester, and a heavy-lift drone for implementing forest operation - The livestock case study takes place in Greece. It aims to improve and promote sheep breeding via grazing and health monitoring on the Greek island of Lesbos. The project was started in September 2022 and will complete in August 2026.
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** The stakeholders of the ecosystem are - Consumers - Farmer - UAS operator - IT solution developers - Regional policy makers Their business expectations are innovative services that will allow for the following: - Reduction in use of pesticides (Crop) - Reduction in water use (crop) - Trees monitored (Terraced crop) - Number of wildfires detected (crop) - Number of invasive species/animals detected (crop) - Forest inventoried (forestry) - Diseases to be monitored (e.g., Lumpy skin disease, bluetongue etc.) (livestock) Higher level goals can include the reduction of deforestation, precision farming and animal welfare.

Figure 13 shows the characteristics of the digital twin:

- The target entity is the agriculture application (culture, forest, livestock)
- The digital entity collects data from agriculture application, uses data science and AI capability.

This digital entity is assisted by UAS. This requires specific building blocks for

- individual UAS usability
- UAS type applicability (e.g., swarm, collaborative, autonomous, tethered)
- UAS governance models availability, and
- UAS generated data trustworthiness.

The digital entity is further using data-oriented capability, e.g., AI capabilities for reasoning and learning.

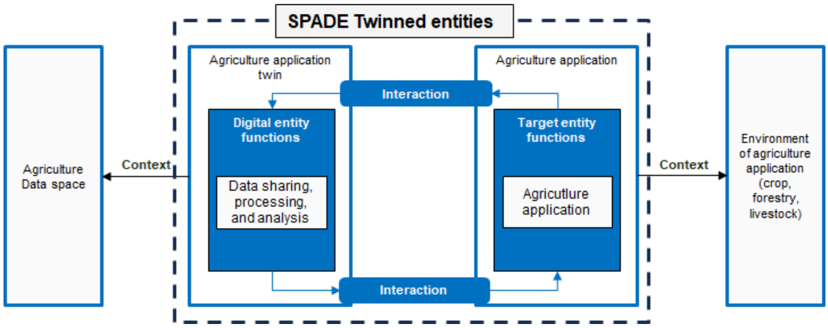


Figure 13 – Digital Twin for agriculture application

Digital twin functions

Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?

The following functions are used

- At inception level, definition of agriculture goals and needs
- At design level, digital twin system design, better understanding and analysis of crop, forestry, livestock
- At deployment level, modelling and simulation of agriculture system, better evaluation of agriculture system
- At operation and monitoring level, reducing operating cost, prediction prognosis.
- At development and verification level, model training and improve simulation, better use of AI, reducing operating cost, prediction prognosis.
- At retirement level, construction of historical database and scientific research.

Table 2 describes maturity dimensions in Table 2). Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?

The following maturity levels are targeted:

- Synchronized level for the convergence dimension
- Predictive level for the capability dimension
- Connected level for the integration dimension
- Linked level for the time dimension

Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?** The following interoperability needs are identified: - Outer interoperability: observation of the field, sometimes acting (e.g. crop production spraying) - Inner interoperability: transmission of observation data from the field to the digital entity, transmission of mission plan to UAS from digital twin. - Transversal interoperability: exchange of agriculture data in the data space Figure 14 shows a sequence diagram involving the three types of interoperability.

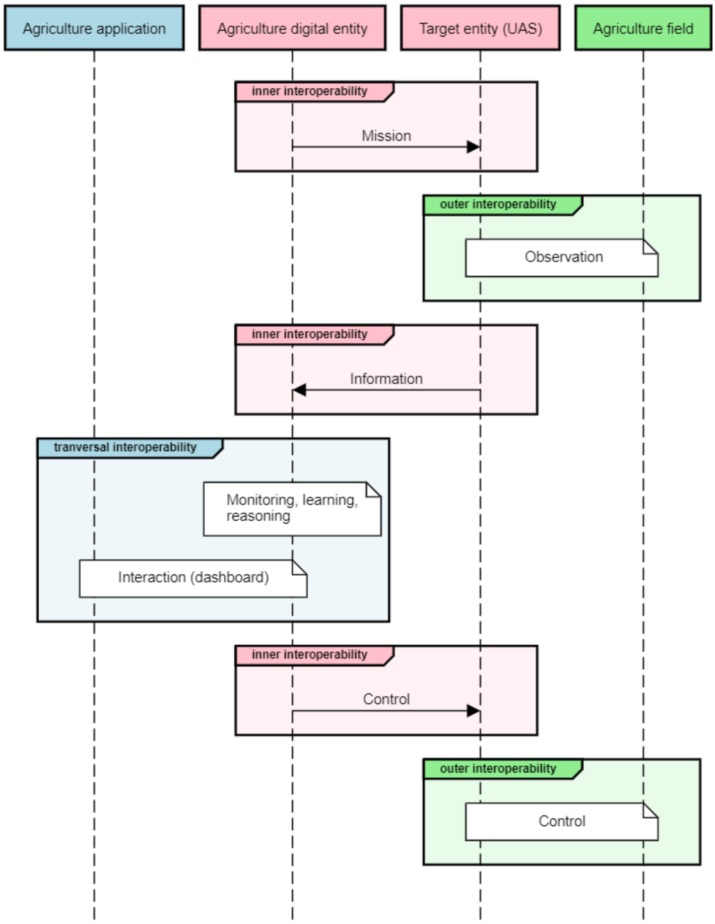


Figure 14 – Interoperability diagram agriculture digital twin

	Sequence diagram code (https:// sequencediagram.org/) participant Agriculture application #lightblue participant Agriculture digital entity #pink partic- ipant Target entity (UAS) #pink participant Agri- culture field #lightgreen group #pink inner interoperability Target entity (UAS)<-Agriculture digital entity:Mission end group #lightgreen outer interoperability note over Agriculture field, Target entity (UAS): Observation end group #pink inner interoperability Target entity (UAS)->Agriculture digi- tal entity:Information end group #lightblue tranversal interoperability note over Agriculture digital entity:Monitoring, learning,\nreasoning note over Agriculture digital entity, Agriculture application:In- teraction (dashboard) end group #pink inner interoperability Target entity (UAS)<-Agriculture digital entity:Control end group #lightgreen outer interoperability note over Agriculture field, Target entity (UAS):Control end
IoT and edge infra-structure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** Digital twins are utilised to monitor and assist agriculture applications through the assistance of UAS to enable data sharing, processing and analysis and enable sustainability and resilience of applications. Multi-purpose UAVs in different configurations are foreseen: - Swarm of drones (< 2 kg) - Cooperative drones (2 kg < < 20 kg) - Large single (> 20 kg) Integration of UAS capability with data space capability integrating AI, IoT and cloud solutions are foreseen.

Data space infra-structure	**Can you describe the data space infrastructure that your digital twins would like to use?** The SPADE infrastructure includes a complex configuration of UAS (smarm of drones, cooperative drones, and heavyweight drone). Management capabilities are included in the infrastructure as showed in Figure 15: - The agriculture application layer includes the high level services leveraging an agriculture data space, crop, forestry, livestock and others. - The agriculture twin layer provides data storage (data space), capability for updating and reasoning on agriculture models, and twin management. - The UAS management layer includes specific capabilities, such as - Individual task assignment including when multiple UAS are used, - Management of UAS operation (e.g., energy consumption), - Cooperation between UAS. Note that the management layer can include other digital twins (e.g. UAS digital twin)

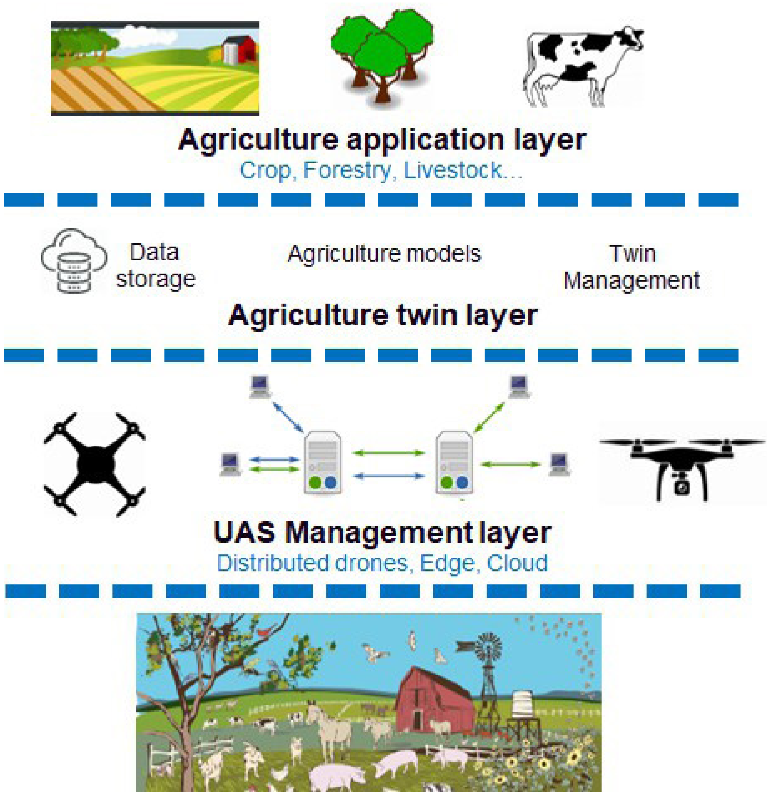


Figure 15 – UAS based infrastructure for agriculture

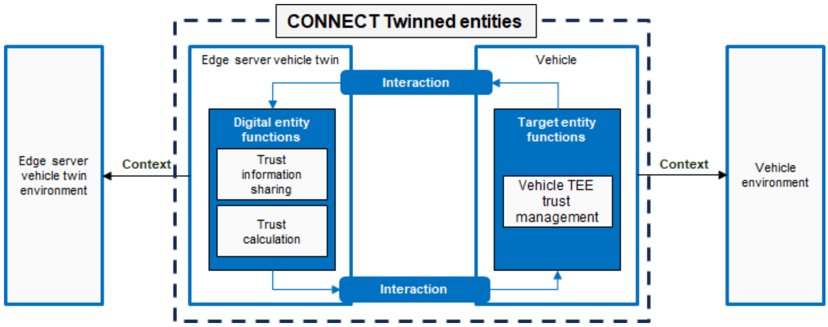
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** The infrastructure is a system of systems. Two level of security concerned must be addressed - Security of the agriculture twin layer including the interactions with the UAS management layer and the access to the agriculture data space Security of the UAS management layer, including the interactions between drones, the interactions of the drones with the agriculture twin layer. Two levels of privacy concerns must be addressed - Privacy in the agriculture twin layer when data collected include personal data (e.g., collected data include information on passers-by or on farmers). This extends to the associated agriculture data space. - Privacy in the UAS management layer when data collected or information related to the UAS are eavesdropped. For instance, in a tethered drone, the moves of the drone will correspond to the move of the farmer.
Other aspects	**Are there other aspects that you would like to report?** No other aspects to report
References	**Provide references (e.g. URL)** - SPADE Horizon Europe project https://spade-horizon.eu/ - SPADE Deliverable D3.1 Report on platform development. Under preparation

3.3 Transport - Connected Vehicles Digital Twin – CONNECT

Table 7 – Connected vehicle – CONNECT

CONNECT: Continuous and Efficient Cooperative Trust Management for Resilient CCAM	
Contact	Thanassis Giannetsos, UBITECH (agiannetsos@ubitech.eu)
Abbreviations	**List abbreviations used in your contribution** CCAM Cooperative, Connected and Automated Mobility Maas Mobility as a Service MEC Mobile Edge Computing MDM Multimodel Digital Mobility RSU Road Side Unit TEE Trusted Execution Environment VEC Vehicle Edge Computing

Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** The Cooperative, connected and automated mobility (CCAM) application domain transforms a driver into a user of a shared fleet of vehicles, fully integrated in a multi-modal transport system, made seamless by Multimodal Digital Mobility (MDM) services such as (Mobility as a service) MaaS. Communication between vehicles, infrastructure and other road users is also crucial to increase the safety of future automated vehicles and their full integration in the overall transport system. Cooperation, connectivity, and automation are not only complementary technologies; they reinforce each other and will over time merge completely. The vision of the project is to address the convergence of security and safety in CCAM by assessing dynamic trust relationships and defining a trust model and trust reasoning framework based on which involved entities can establish trust for cooperatively executing safety-critical functions. The CONNECT Trust Management framework is the basis that models and captures the trust relationships of the next generation CCAM systems. Subjective logic is used to combine subjective and objective assessment. CONNECT's new safety paradigm is a key element in bringing autonomous driving to a completely new level of trustworthiness and is expected to lead to long-term consumer acceptance as a result. The project was started in September 2022 and will complete in August 2025
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** The stakeholders of the ecosystem are - Driver - Vehicles and road users, including pedestrians and cyclists - Vehicle manufacturer - Mobile operator - CCAM service provider Their business expectations as stated in the CCAM strategic research and innovation agenda are the following - increased connectivity with vehicles and the infrastructure allowing vehicles to better coordinate their maneuvers - active infrastructure support for improved throughput and increased safety - enabling smart traffic and fleet management Higher level goals can include shared, automated mobility and freight services, seamless door-to- door mobility for people and goods including fully autonomous last mile deliveries. This can lead to healthier, safer, more accessible, greener, cost effective, demand-responsive and more sustainable transport everywhere. Figure 16 shows the intended CONNECT digital twin architecture: - The digital twin entity of interest combines the **edge server vehicle twin** (in charge of assistance functions) and the **vehicle** (in charge of target functions), - The target function is the vehicle Trusted Execution Environment (TEE) trust management - The assistance function consists of the trust calculation capability as well as the distributed trust information sharing capability. - The environment of the CONNECT digital twin includes the vehicle environment and the edge server vehicle twin environment. - The interactions between the edge server vehicle twin and the vehicle are the following: the edge server vehicle twin is offloading the system by carrying trust calculation capabilities. It does so through two interfaces, a point of observation (PO) interface and a point of control (PC) interface. The PO is used to provide real-time information that allows the edge server vehicle twin to calculate trust.

	 **Figure 16 – Digital Twin for TEE trust management offloading**
Digital twin functions	**Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?** The following functions are used - At inception level, definition of trust assessment framework goals and needs, vehicle moves models. - At design level, digital twin system design, simulation of digital twin, better understanding and analysis of CCAM trust - At deployment level, modelling and simulation of CCAM cases, visualization capabilities, better evaluation of overall trust from vehicle viewpoint - At operation and monitoring level, real-time and visual monitoring, reducing operating cost, alarming, prediction prognosis. - At development and verification level, reducing operating cost, prediction prognosis. - At retirement level, construction of historical database and scientific research. **Table 2 describes maturity dimensions in Table 2). Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?** The following maturity levels are targeted: - Federated level for the convergence dimension - Predictive level for the capability dimension - System views level for the integration dimension - Synchronized level for the time dimension
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?** The following interoperability needs are identified: - Outer interoperability: observation of the CCAM environment - Inner interoperability: exchange of trust information further to trust calculation. - Transversal interoperability: exchange of trust data between vehicles Figure 17 further shows distributed architecture requirements of the vehicle twins; - Individual vehicle twins are allocated to a given edge server according to a trustworthy registration, deployment and handover capability provided by the MEC (this capability is not addressed in CONNECT research work) - Each individual vehicle twin can access a number of facilitating functions such as communication assistance, data and behaviour logger, digital asset ownership management information, security and privacy of exchange.

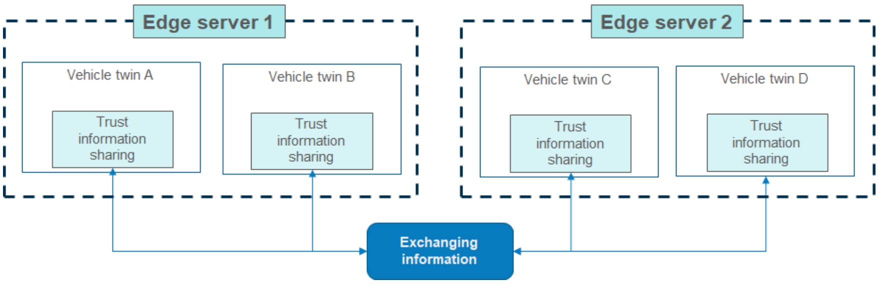


Figure 17 – Distributed information sharing between vehicle twins

Figure 18 shows a sequence diagram involving the three types of interoperability. Three entities are involved: vehicle, vehicle twin, and distributed trust manager.

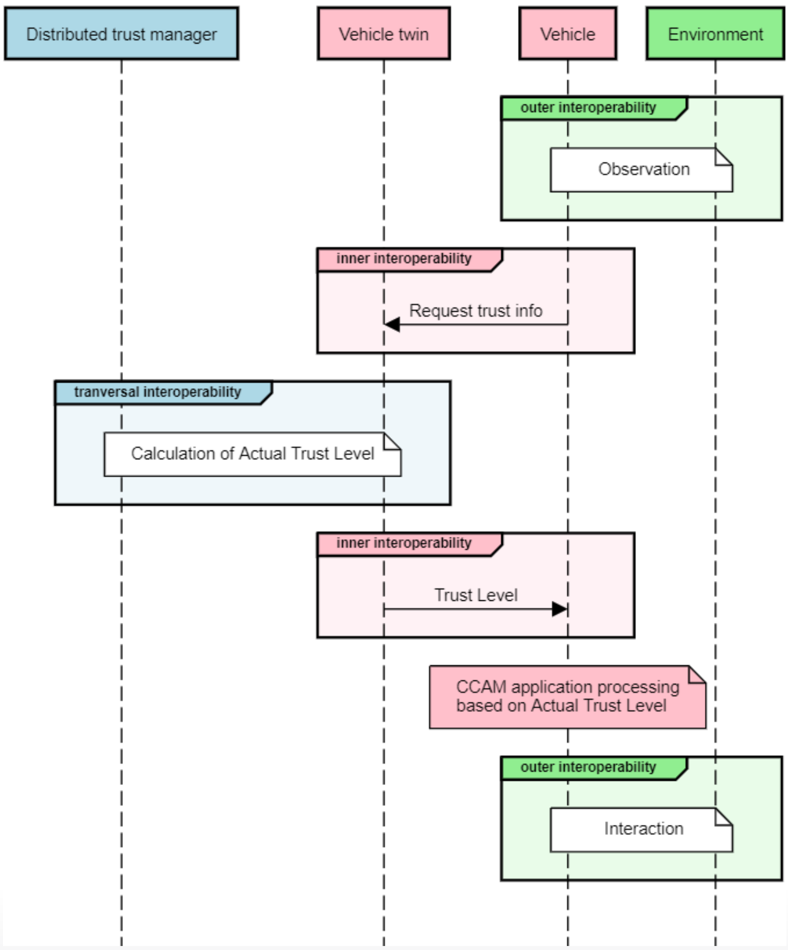
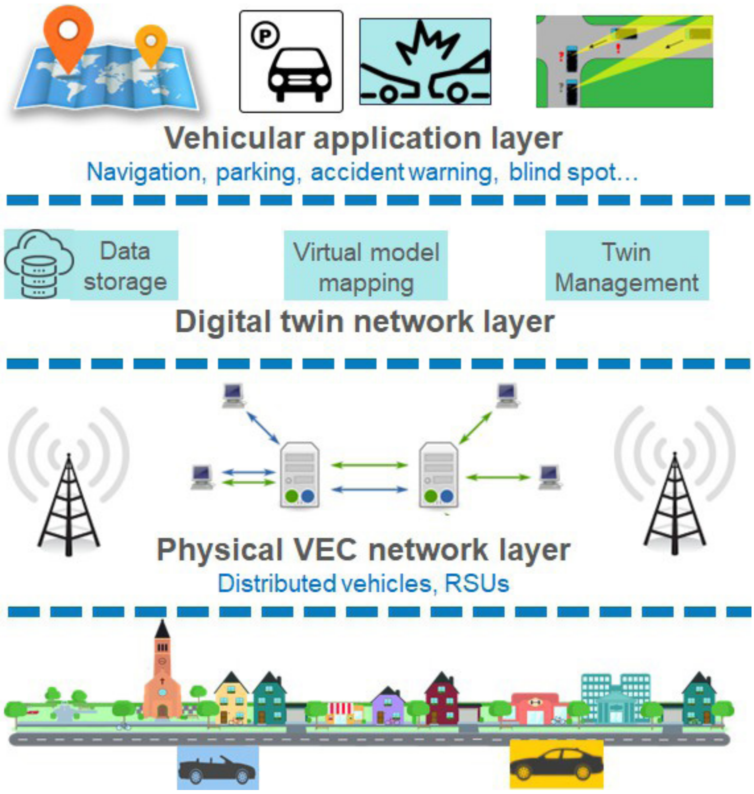


Figure 18 – Sequence diagram of connected vehicle use case

	Sequence diagram code (https://sequencediagram.org/) participant Distributed trust manager #lightblue participant Vehicle twin #pink participant Vehicle #pink participant Environment #lightgreen group #lightgreen outer interoperability note over Vehicle, Environment: Observation end group #pink inner interoperability Vehicle->Vehicle twin:Request trust info end group #lightblue tranversal interoperability note over Vehicle twin,Distributed trust manager:Calculation of Actual Trust Level end group #pink inner interoperability Vehicle<-Vehicle twin:Trust Level end note over Vehicle #pink :CCAM application processing\nbased on Actual Trust Level group #lightgreen outer interoperability note over Vehicle, Environment: Interaction end
IoT and edge infrastructure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** Digital Twins are utilised to simulate the complete lifecycle of a system in order to facilitate autonomous driving tests. This enables the assessment of the performance of connected autonomous driving systems in controlled settings. Moreover, the concept of Digital Twins has been expanded to encompass various scenarios, such as communication between vehicles and traffic lights, as well as interactions between vehicles at intersections.

Data space infrastructure	**Can you describe the data space infrastructure that your digital twins would like to use?** The architectural framework is showed in Figure 19. It comprises a physical VEC (Vehicule Edge Computing) network, managing distributed vehicles and RSUs, a digital twin network layer, and a layer dedicated to vehicular applications. The digital twin network layer is responsible for tasks such as model construction (vehicle model, RSU model, network model), item mapping, and strategy optimization).  **Figure 19 – Digital twin based on vehicle edge computing**
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** - Two types of security to be addressed at the digital twin level, the intra twin security (e.g., security of interactions between the digital entity and the target entity), and the inter twin security (e.g., security of exchanging information between the twins). - The following to be addressed at the mobile network level, secure handover to enable the secure migration of historical data from a source edge server to the new edge server, and secure and lightweight communication protocol: to achieve low communication overhead and reducing latency. - Enforcement of privacy in edge servers requires (1) protection of transmitted data, (2) enforcement of usage, (3) ensuring unlinkability to vehicles (tracking vehicles should be facilitated by the tracking of their twins)

Other aspects	**Are there other aspects that you would like to report?** CONNECT is using subjective logic to model and analyse situations involving uncertainty and potentially less reliable sources. We hope to validate this approach and to pave the way to a framework for trustworthiness in other domains, including AI
References	**Provide references (e.g. URL)** - Subjective logic: https://en.wikipedia.org/wiki/Subjective_logic - Cooperative, connected and automated mobility (CCAM) https://transport.ec.europa.eu/transport-themes/intelligent-transport-systems/cooperative-connected-and-automated-mobility-ccam_en - 5G-CARMEN Horizon Europe project. https://5gcarmen.eu/ - DIGEST project. https://projekte.ffg.at/projekt/3894859 - CONNECT Horizon Europe project https://horizon-connect.eu/ - CONNECT Deliverable D2.1 Architecture and requirements. Under preparation. - CCAM Strategic Research and Innovation Agenda. https://www.ccam.eu/wp- content/uploads/2022/05/CCAM_SRIA-report_web.pdf

3.4 Smart city digital twin – URBREATH

Table 8 – Smart city digital twin – URBREATH

URBREATH	
Contact	Giuseppe Ciulla, Engineering (giuseppe.ciulla@eng.it) Roberto Di Bernardo, Engineering (roberto.dibernardo@eng.it)
Abbreviations	**List abbreviations used in your contribution** NBS: Nature Based Solution
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** The URBREATH project puts into action and validates a comprehensive approach to urban revitalisation, resilience, and climate neutrality, which is driven by community participation and Natural Base Solutions (NBS), with a focus on enhancing social interactions, inclusion, equitability, and liveability in cities. The project places communities at the core of the decision-making process, aiming for a blend of traditional and Natural Base Solutions. The project employs advanced techniques, notably Local Digital Twins and Artificial Intelligence (AI) which are part of the URBREATH technical framework, a set of tools designed to manage the entire data value chain and assist end- users in collaborating on the design and creation of NBSs. This technical framework will be used to monitor and make decisions on the NBSs to be implemented in four Front Runner Cities, each located in a different climatic zone: Cluj-Napoca (Continental - Romania), Leuven (Atlantic - Belgium), Madrid (Mediterranean - Spain), and Tallin (Boreal - Estonia).

	Information, results, and lessons learned will be gathered and analysed to provide recommendations and encourage replication activities, as well as the adoption of project outputs. To this end, five Follower Cities are involved: Aarhus (Denmark), Athens (Greece), Kajaani (Finland), Parma (Italy), and Pilsen (Czech Republic). These cities are linked to the Front Runners based on their climatic zone and/or size. Even if the URBREATH project is in its early stage (the project started on January 2024) it already identified key building elements, such as related to integration with data spaces.
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** The stakeholders of the ecosystems are: - Civil servants - Policy makers - Urban planners - Citizens - Local citizens associations - Local business activities Their business expectations are related to green urban planning and urban services & infrastructures for all segments of population, taking into account climate change and socioeconomic aspects. Figure 20 shows the high-level architecture of the URBREATH technical framework - The real world entity is the urban environment (infrastructures, buildings, furniture, green areas, trees, etc.) - The digital entity gathers information about the urban environment from a variety of sources, including data repositories, existing IT systems, and Internet of Things (IoT) devices. It provides services such as analysis, simulations, and other services for decision-makers, including ex-ante and ex-post analysis, impact assessment, among others.

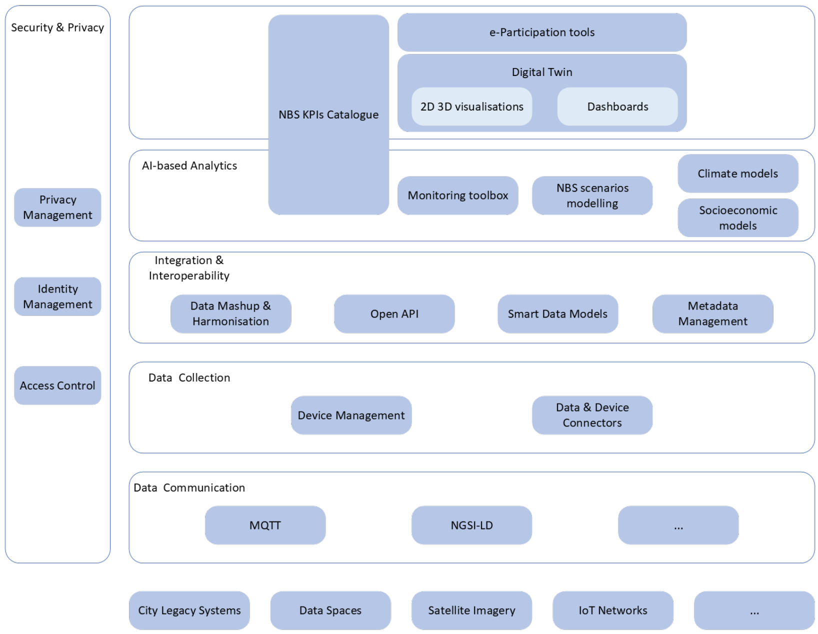


Figure 20 – URBREATH technical framework, high-level architecture

Digital twin functions

Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?

The following functions are used

- At inception level, definition of urban greening planning according to socioeconomic needs and adaptation to climate changes, reinforced through a participatory process.
- At design level, digital twin design, better understanding of needed analysis and simulations, selection of tools, techniques and data, visual design of the functionalities for policy makers and stakeholders, integrating e-participation capabilities.
- At deployment level, modelling and simulation of urban environment focusing on greening, socioeconomic and climate changes needs of diverse segments of the population and stakeholders, towards NBS planning, implementation and impact monitoring.
- At operation and monitoring level, plan more suitable NBS to reduce climate change effects, that are identified and planned together local stakeholders.
- At development and verification level, model training and improve simulation, better use of AI, reducing operating cost.
- At retirement level, construction of historical database and scientific research.

Table 2 describes maturity dimensions in Table 2). Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?

The following maturity levels are targeted: Synchronized level for the convergence dimension

- Optimized - Prescriptive level for the capability dimension
- Connected level for the integration dimension
- Linked level for the time dimension

Interoperability

Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?

The following interoperability needs are identified:

- Outer interoperability: observation of the field, planning of NBS interventions.
- Inner interoperability: transmission of data collected from local repositories and the field to the digital entity; provision of analysis/simulation results to policy makers / urban planners from digital twin.
- Transversal interoperability: exchange of urban related data in the data space

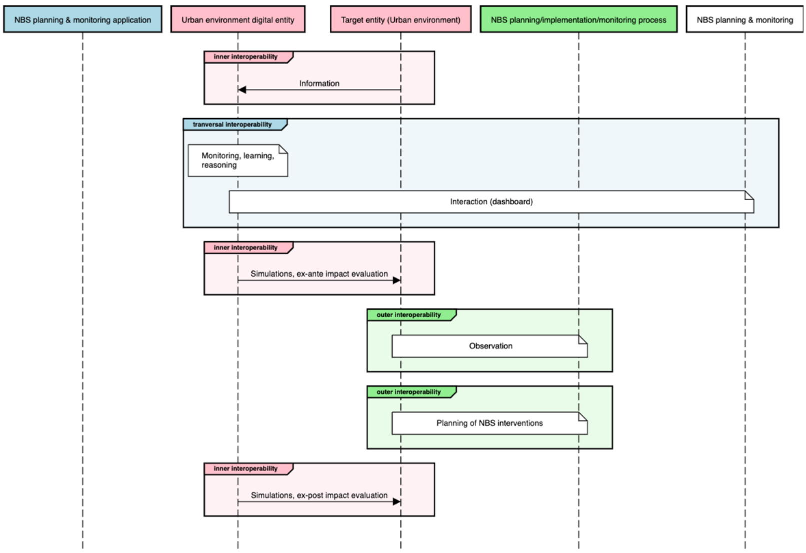


Figure 21 – Interoperability diagram urban digital twin

participant NBS planning & monitoring application #lightblue participant Urban environment digital entity #pink participant Target entity (Urban environment) #pink

participant NBS planning/implementation/monitoring process #lightgreen

group #pink inner interoperability

Target entity (Urban environment)->Urban environment digital entity:Information end

group #lightblue transversal interoperability

note over Urban environment digital entity: Monitoring, learning,\nreasoning

note over Urban environment digital entity, NBS planning & monitoring: Interaction (dashboard) end

group #pink inner interoperability

Target entity (Urban environment)<-Urban environment digital entity: Simulations, ex-ante impact evaluation

end

	group #lightgreen outer interoperability note over NBS planning/implementation/monitoring process, Target entity (Urban environment): group #pink inner interoperability Target entity (Urban environment)<-Urban environment digital entity:Simulations, ex-post impact evaluation end Observation end group #lightgreen outer interoperability note over NBS planning/implementation/monitoring process, Target entity (Urban environment):Planning of NBS interventions end
IoT and edge infrastructure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** Digital twin is used to monitor the urban environment and assist policy makers in planning NBS related interventions towards green cities. The digital twin leverages IoT/edge capabilities to collect feedback from local stakeholders and engage them into participatory process for urban planning.
Data space infrastructure	The URBREATH technical framework includes a data management layer to oversee entire process of data management, including discovery, analysis, harmonisation, simplifying access to the data, thereby to address issues such as varying data formats, the absence of a single access point to the data, fragmented ownership, lack of data interoperability, and the resulting isolation of data ("data silos"). The data management layer will rely on open-source technologies, utilising open and standardised interfaces, such as NGSI-LD and DCAT-AP to build an infrastructure for trustworthy data sharing and exchange, allowing for adoption of common APIs and security schemas and enabling the interaction with data spaces (following the EU Initiative like DS4SSCC, DSSC).
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** The URBREATH technical framework includes Privacy and Security layer, which encompasses all security aspects associated with the data lifecycle, providing features related to confidentiality, authentication, authorization, and access control, as well as compliance with applicable regulations concerning data privacy, such as GDPR, and other national or sectoral legislation ensures that data privacy, availability, integrity, and confidentiality. It's functionalities will be implemented leveraging the capabilities offered by tools such as Keycloak (a tool that allows to manage users, roles, authentication & authorization procedures, which is compliant with standard protocols such as OAuth 2.0 and SAML 2.0).
Other aspects	**Are there other aspects that you would like to report?** No other aspects to report
References	**Provide references (e.g. URL)** URBREATH Horizon Europe project https://urbreath.eu/

3.5 Smart City digital twin – URBANAGE

Table 9 – Smart city digital twin – URBANAGE

URBANAGE	
Contact	Giuseppe Ciulla, Engineering (giuseppe.ciulla@eng.it) Roberto Di Bernardo, Engineering (roberto.dibernardo@eng.it)
Abbreviations	**List abbreviations used in your contribution** - TRUE: TRUsted Engineering
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** Disruptive technologies bear great potential to transform the way public services are delivered. Their advantages are quite clear in some sectors, but less clear or experimented within others, which generates uncertainty and lack of trust. Urban Planning, considering that 75% of the population lives in urban areas, could greatly benefit from using disruptive technologies. Moreover, when using disruptive technologies there is a risk of excluding some parts of the population. Older adults, for example, are less digitally literate but represent a large part of the population in today's European aging cities. It is, therefore, of crucial importance to engage them in the decision-making process to make sure solutions respond to their needs and capacities. In this context, URBANAGE contributes to a more inclusive decision-making. It develops an Ecosystem that improves the quality of decision-making on issues related to urban planning for age- friendly cities, by harnessing the collective intelligence of users. For this purpose, URBANAGE aims to provide evidence-based tools for local authorities to guide transformation towards more inclusive cities while exploring how existing engagement tools can be adapted to senior citizens' needs. Moreover, URBANAGE will assess if active engagement has a positive impact on the trust levels observed among older people and public servants concerning data and digital tools, and on the perceived value of technology-assisted urban planning decision-making.
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** The stakeholders of the ecosystems are: - Civil servants - Policy makers - Urban planners - Older adults Their business expectations are related to age friendly urban planning and urban services & infrastructures for older adults: - safe and physical accessible city - promote age-friendly cities in context where population is getting older - address the needs of older people in the cities - access to real time information of the urban infrastructure to be maintained

- new strategies to collect information from older adults about their needs and preferences
- inform older adults about the available initiatives and resources
- new strategies on how to reach older citizens that are isolated.

Figure 22 shows the high-level architecture of the URBANAGE Ecosystem Platform

- The real world entity is the urban environment (infrastructures, buildings, furniture, green areas, trees, etc.)
- The digital entity collects data about the urban environment from diverse sources (data repositories, legacy IT systems, IoT devices, etc.), and offers analysis, simulations and services for policy makers (e.g. simulations for long term urban planning, analysis of accessibility issues) and older adults (e.g. age-friendly route planner).

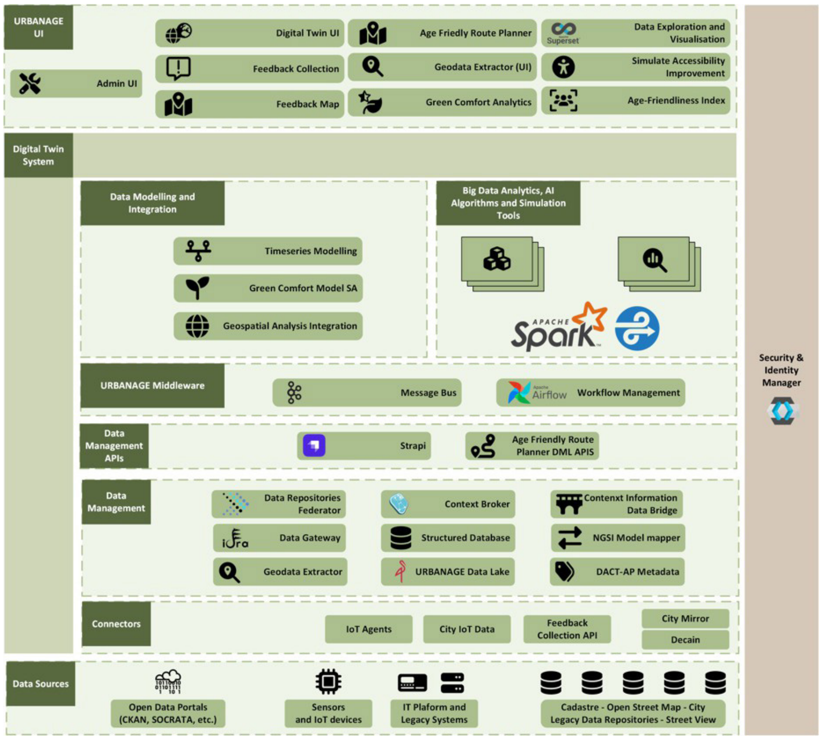


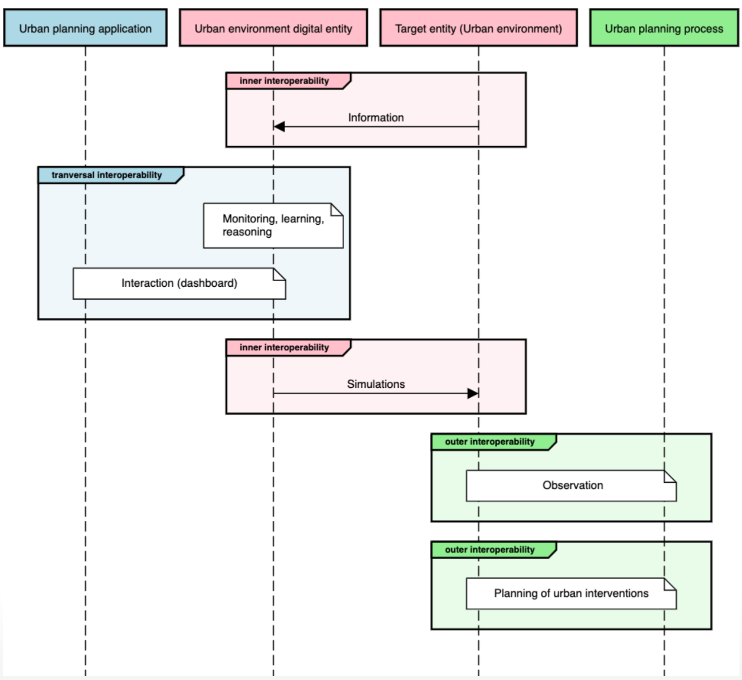
Figure 22 – URBANAGE Ecosystem Platform, high-level architecture

Digital twin functions

Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?

The following functions are used

- At inception level, definition of older adults and needs and urban planning challenges and goals
- At design level, digital twin system design, better understanding of needed analysis and simulations, selection of tools, techniques and data, visual design of the functionalities for policy makers and older adults.
- At deployment level, modelling and simulation of urban environment focusing on needs of older adults, better evaluation of urban planning in the short and long term

	- At operation and monitoring level, reducing operating cost for urban planning (having more detailed plans that considers needs of a growing segment of the population). - At development and verification level, model training and improve simulation, better use of AI, reducing operating cost. - At retirement level, construction of historical database and scientific research. **Table 2 describes maturity dimensions in Table 2). Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?** The following maturity levels are targeted: - Synchronized level for the convergence dimension - Optimized - Prescriptive level for the capability dimension - Connected level for the integration dimension - Linked level for the time dimension
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?** The following interoperability needs are identified: - Outer interoperability: observation of the field, planning of urban interventions. - Inner interoperability: transmission of data collected from local repositories and the field (feedback provided by older adults) to the digital entity; provision of analysis/simulation results to policy makers from digital twin. - Transversal interoperability: exchange of urban related data in the data space - Transversal interoperability: exchange of urban related data in the data space  **Figure 23 – Interoperability diagram urban digital twin**

	participant Urban planning application #lightblue participant Urban environment digital entity #pink participant Target entity (Urban environment) #pink participant Urban planning process #lightgreen group #pink inner interoperability Target entity (Urban environment)->Urban environment digital entity:Information end group #lightblue tranversal interoperability note over Urban environment digital entity:Monitoring, learning,\nreasoning note over Urban environment digital entity, Urban planning application:Interaction (dashboard) end group #pink inner interoperability Target entity (Urban environment)<-Urban environment digital entity:Simulations end group #lightgreen outer interoperability note over Urban planning process, Target entity (Urban environment): Observation end group #lightgreen outer interoperability note over Urban planning process, Target entity (Urban environment):Planning of urban interventions end
IoT and edge infrastructure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** Digital twin is used to monitor the urban environment and assist policy makers in planning interventions in the short and long term towards age friendly cities. The digital twin leverages IoT/edge devices to collect feedback from older adults about issues they encounter in the city and to offer them dedicated functionalities (e.g. age friendly route planner).
Data space infrastructure	**Can you describe the data space infrastructure that your digital twins would like to use?** The architecture of the URBANAGE Ecosystem Platform includes a layer devoted to data collection, harmonization, integration and interoperability. It leverage diverse connectors to allow the interconnection and data exchange with different sources and systems. Among them the URBANAGE Connector for IT Platforms, which offer a preparation for the interconnection with Data Spaces.

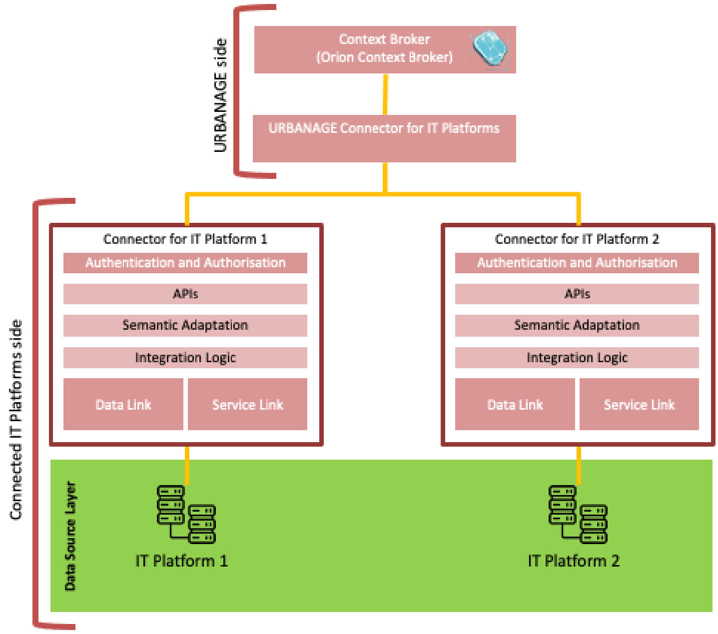


Figure 24 – URBANAGE Connector for IT Platforms

The URBANAGE Connector for IT Platforms is a two-part system that connects the URBANAGE Platform to other IT Platforms. It consists of several logical layers:

- **Authentication and Authorisation Layer**: Protects the connector from external attacks and prevents data leaks.
- **APIs Layer**: Implements REST APIs for interaction between the Data Management Layer and the connector. The APIs follow the IDS connector provided by the TRUE Connector and expose three endpoints: /proxy, /data, and /about/version.
- **Semantic Adaptation Layer**: Translates the exchanged data according to the data models managed by the URBANAGE Platform (i.e., NGSI-LD based).
- **Integration Logic Layer**: Performs procedures for the correct integration of the connector
- with the specific IT Platform. It accesses data and interacts with services of the specific IT Platform through the Data Link and Service Link layers. It can also anonymise data if needed.
- **Data Link Layer**: Enables the Integration Logic layer to access the data managed by the specific IT Platform.
- **Service Link Layer**: Enables the Integration Logic layer to interact with services exposed by the specific IT Platform.

The implementation of these layers depends on the policies, technical characteristics, restrictions, requirements, etc., of the specific IT Platform. Detailed information is available in the TRUE Connector's official documentation.

Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** The URBANAGE Ecosystem platform includes a Security & Identity Manager layer, which ensures its protection from unauthorized access. It implements a series of security measures across all layers of the platform, including: - Secure Protocols: Uses HTTPS for communications involving publicly available APIs. - Firewall: Allows traffic flow only through specific ports and domains to the platform's services. - Access Control: Grants remote or physical access to servers only to authorised personnel. - Data Protection: Employs hashing/encryption of user passwords. - Authentication: Manages user and role authentication for accessing the platform's functionalities. For implementing security measures related to users and roles management, and authentication authorization procedures, the platform uses the open-source tool Keycloak, which offers features like centralized management, compliance with standard protocols (OAuth 2.0, SAML 2.0, etc.), and Single Sign-On (SSO).
Other aspects	**Are there other aspects that you would like to report?** No other aspects to report
References	**Provide references (e.g. URL)** - URBANAGE Horizon 2020 project *https://www.urbanage.eu/* - URBANAGE Deliverable D5.6 System Architecture Final. Under approval

3.6 Energy digital twin – digital twin substation data sharing

Table 10 – Digital twin substation data sharing

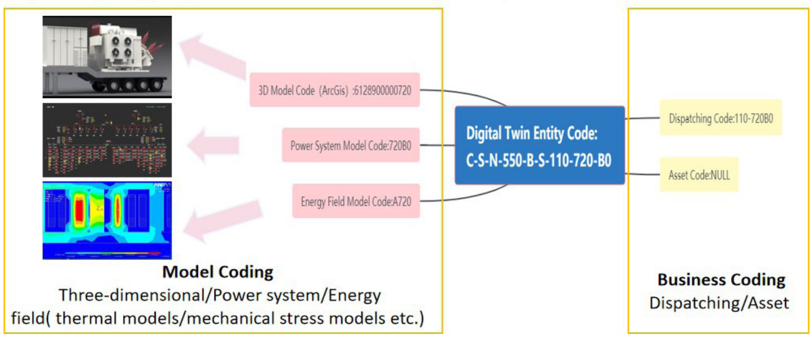
<table>
<tr><th colspan="2">Digital twin substation data sharing based on data space</th></tr>
<tr><td>Contact</td><td>Jieshan Li, China Southern Power Grid (583312084@qq.com)</td></tr>
<tr><td>Abbreviations</td><td>List abbreviations used in your contribution
DTw Digital Twin</td></tr>
<tr><td>Description</td><td>The goal of this project is to develop a digital twin that brings together a 3D model of the power grid, a model of the power system, and a model of the energy field, with data interaction on the data space.
The three types of data are interacted through data twin entity coding. The project was completed in November 2022.


Figure 25 – Digital twin substation 3-D model of powergrid
There are five steps to integrate the systems data together:</td></tr>
</table>

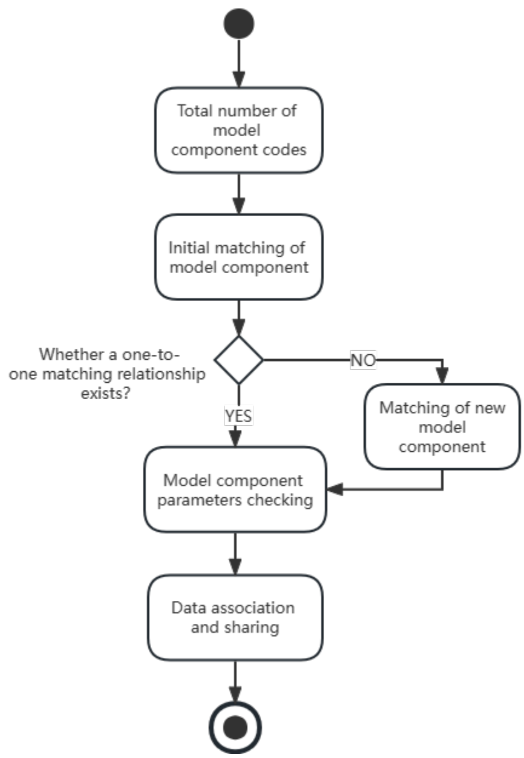
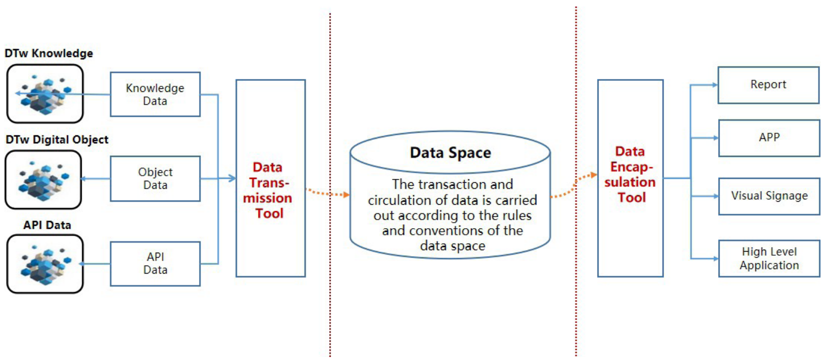
<table>
<tr>
<td></td>
<td>


Figure 26 – Digital twin substation system data integration steps
- Calculating and checking the total number of codes for energy field model, physical entity model and power system model respectively
- Making book standing information list and basic information list comparison between models. Unmatched data is marked.
- Data of the newly added model component is compared with each other.
- In the data matching process, all kinds of parameters should meet corresponding constraints.
- Model component with one-to-one matching relationship can conduct data association and information sharing.
</td>
</tr>
<tr>
<td>Digital twins</td>
<td>
Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)
The stakeholders of the ecosystem are
- 3D model data provider
- Power operation model data provider
- Energy field model data provider
- Transmission service user
- Transformer business application user
- Power generation business user
- Power distribution business application
Their business expectations that will allow for the following:
- Better develop the business of power generation, transmission, distribution and consumption
</td>
</tr>
</table>

Digital twin functions	**Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?** The following functions are used - Simulation of digital twin implementation process - Better understanding and analysis of physical entities - Reduce system cost - Realize design optimization - 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.
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?**  **Figure 27 – Digital twin substation Interoperability approach** - DTw system of one company is divided into knowledge, objects and API data. - Data of DTw are transferred to the data space through the data transmission tool. - According to the operation rules of the data space the data can be shared to other company. - The data finally become products through the data encapsulation tool, including: report, APP, Visual Signage, High Level Application.

<table>
<tr>
<td>IoT and edge infrastructure</td>
<td>

Can you describe the IoT and edge infrastructure that your digital twins would like to use?

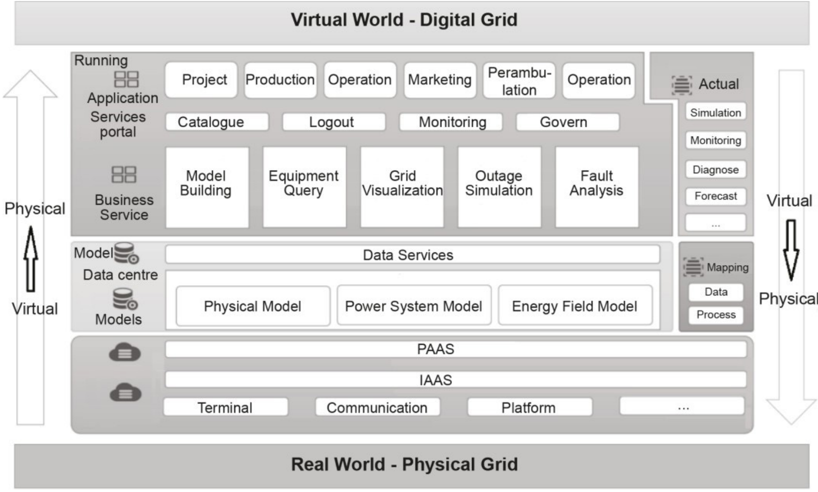


Figure 28 – Digital twin substation IoT and Edge infrastructure

From bottom to top, the reference architecture of this use case consists of the following parts.

The underlying data collection part mainly collects all kinds of power grid operation data through intelligent devices and the Internet of Things, which realizes data aggregation and storage by using cloud computing technology and cloud platform.

</td>
</tr>
<tr>
<td>Data space infrastructure</td>
<td>

Can you describe the data space infrastructure that your digital twins would like to use?

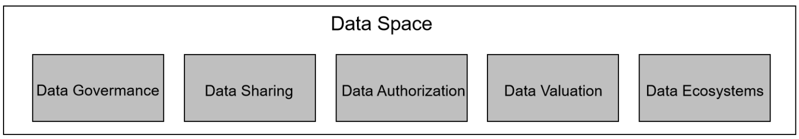


Figure 29 – Digital twin substation Data space

Data space includes data governance, data ecology, data sharing, data value and data authorization.

- Data governance: development and enforcement of policies related to the management of data. Principles of information technology governance including strategy, acquisition, performance, conformance, human behaviour also apply to data.
- Data sharing: access to or processing of the same data by more than one authorized entity.
- Data authentication :authentication of the sender of the data and provision of data integrity.
- Data valuation: process of determining the current value of data as asset, Valuation methods and bases are numerous and varied and may be expressed quantitatively and in monetary terms. Application may be made to a single data asset, a group of data assets, as determined by various bases and methods.

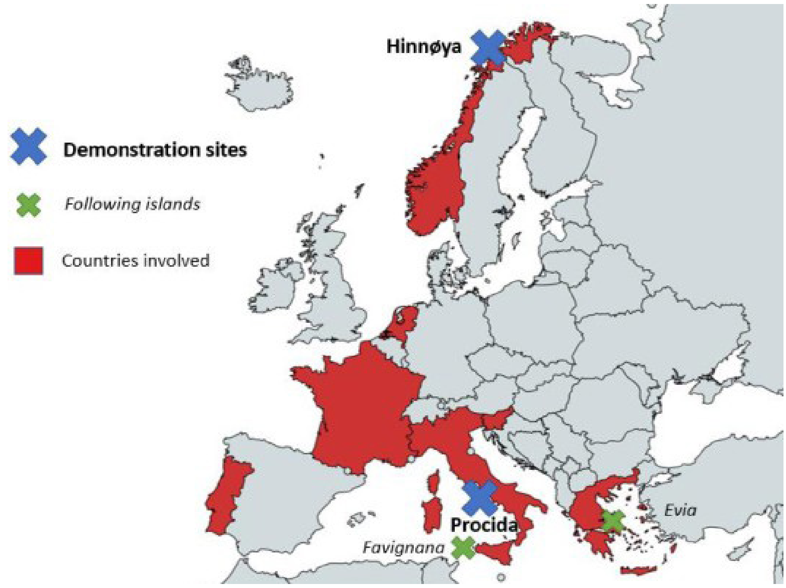
</td>
</tr>
</table>

	Data ecosystem: infrastructure and services based on a network for data sharing of organizations and stakeholders. Organizations can include public bodies.
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** The network security technology involved in this case covers three aspects: system, network, and information. The application of these technologies not only avoids loss or destruction of data during storage, processing and transmission, but also ensures optimal security for the grid digital twin construction within specified performance, time and cost rang.
Other aspects	**Are there other aspects that you would like to report?** No other aspects to report
References	**Provide references (e.g. URL)** No references to report

3.7 Energy digital twin – GIFT

Table 11 – Energy digital twin – GIFT

GIFT: Geographical Islands FlexibiliTy	
Contact	**Provide a contact point** Steiner Igor, Inea (Igor.Steiner@inea.si), Lizhen Huang, NTNU (Lizhen.huang@ntnu.no), Asbjørn Hovstø, Hafenstrom (asbjorn.hovsto@hafenstrom.com)
Abbreviations	**List abbreviations used in your contribution** BMS Building Management System DSO Distribution System Operator DR Demand Response EMS Energy Management System TSO Transmission System Operator VPS Virtual Power System
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** GIFT is a project funded by the European Commission, that was launched in January 2019 and completed in June 2023. It aims to decarbonize the energy mix of European islands. Therefore, GIFT is willing to develop innovative systems to allow islands to integrate large share of renewable energies while not adding stress to the grid, through the development of multiple innovative solutions, that will be combined into a complex system. These solutions include a virtual power system, better prediction of supply and demand and visualization of those data through a GIS platform, and innovative storage systems allowing synergy between electrical, heating and transportation networks.

	It will moreover help to implicate the consumers in the energy transition, through various, energy management systems for harbors, factories, homes and mobility that are being developed within the project. In order to be representative and relevant when proposing solutions at the EU level, GIFT has selected several islands and demonstration sites having their own issues and specificities. The GIFT partners will therefore develop and demonstrate the solutions in two lighthouse islands, Hinnøya, Norway's largest island, and Procida, a small island in Italy, and study the replicability of the solution at least in the Greek island of Evia and the Italian island of Favignana.  **Figure 30 – GIFT Pilots** The GIFT solutions to reach these objectives: - Grid IT platform for visualisation, geographic visualisation, grid observability, prospective modelling and long-term assessment. - VPS system, a decentralised automatic demand response trading platform, connecting DR providers, intermediaries and DR users that is coupled with Flex Agents, installed at DR providers - Prosumers or smart energy consumers that postpone energy demanding tasks or select alternate sources for energy to reduce the load on the power grid, thus providing flexibility.
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** The stakeholders of the ecosystem are - Prosumers - DSO/TSO - Municipalities - IT solution developers - Regional policy makers

Their business expectations are innovative services that will allow for the following:

- Reduction of congestions
- Reduce of the energy bill
- Reduce of the CO2 emissions
- Reduce of the operational cost
- Reduce of the investment
- Allow a high level of local renewable energy sources penetration

Figure 31 shows the Digital twin role in the whole GIFT ecosystem and its main characteristics:

- Provide visibility of the energy grid to better manage its flexibility and plan its evolutions
- One shop solutions for final user on data, information and knowledge for decision making

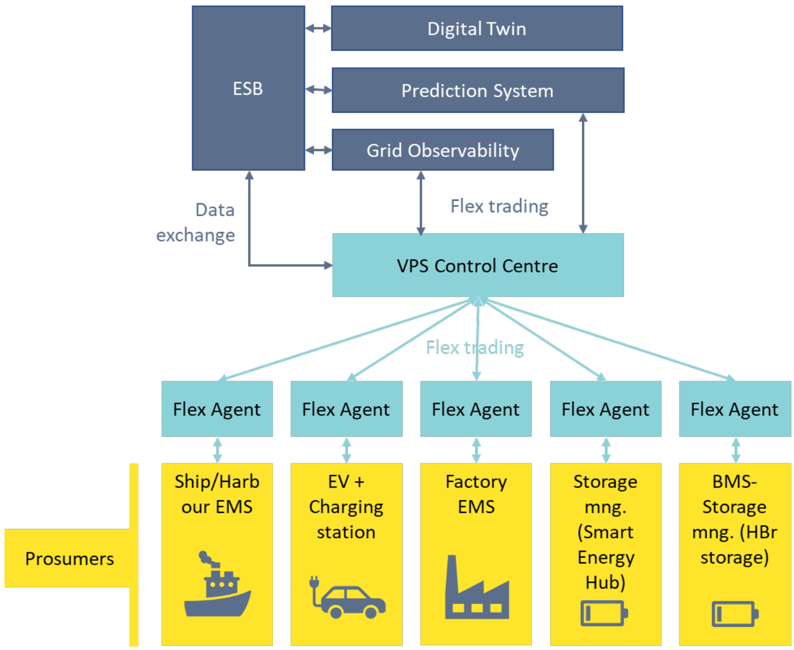


Figure 31 – Digital twin in GIFT ecosystem

Digital twin functions

Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?

The main functions of GIS based digital twin in GIFT are

- One shop visualizing and monitoring system for the state (Historic, real time, forecasted) of infrastructure (Grid, charging station), energy supply, demand and exchange for prosumers, environment and social-economic context of pilots.
- The consequence of "what if" scenarios to support the decision-making.

	Table 2 describes maturity dimensions in Table 2). Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions? The following maturity levels are targeted: - Synchronised level for the convergence dimension - Predictive level for the capability dimension - Connected level for the integration dimension - Linked level for the time dimension
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?** The following interoperability needs are identified: - Outer interoperability: observation of the energy system: including field (i.e. temperature), grid (i.e. active power and reactive power at substations) and prosumers (i.e. smart meter, energy management system) - Inner interoperability: transmission of observation data from field, grid and prosumers to the Energy digital entity, transmission of Energy digital entity to digital twin. - Transversal interoperability: exchange of energy data in the data space Figure 32 shows a sequence diagram involving the three types of interoperability.

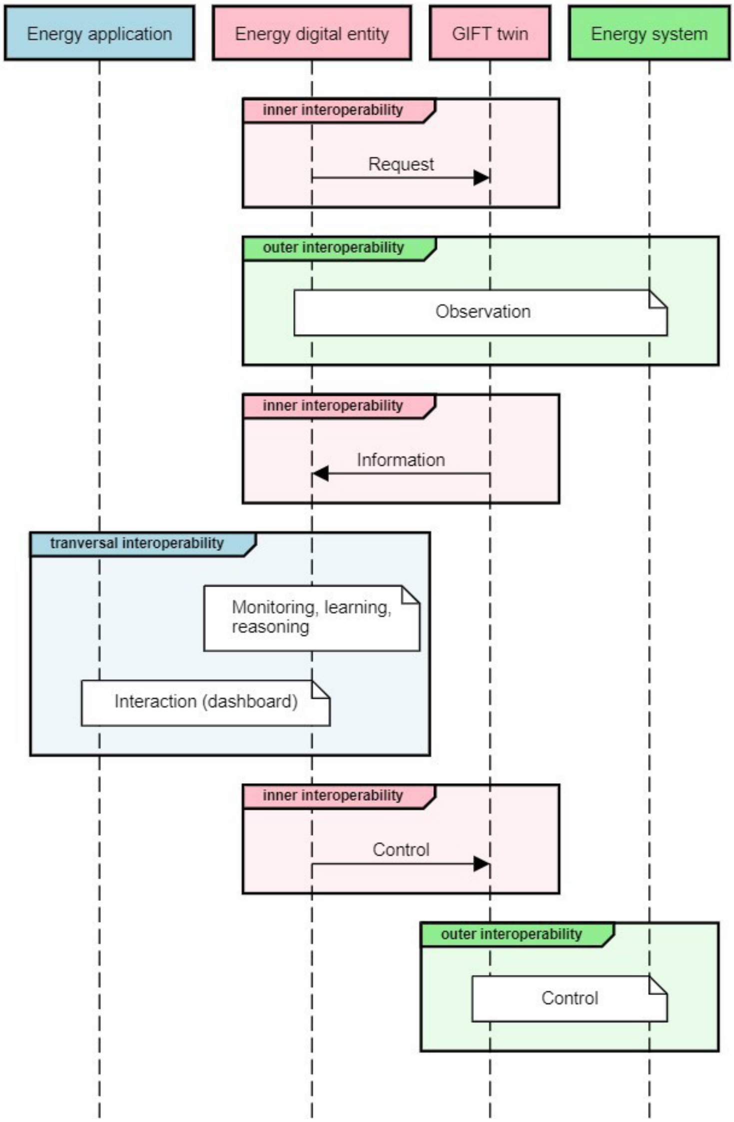


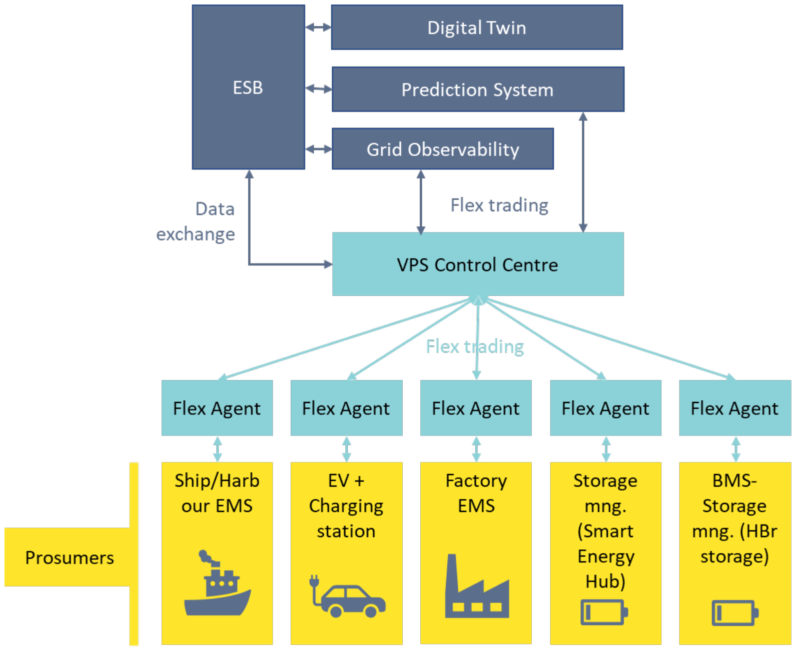
Figure 32 – Interoperability diagram digital twin

Sequence diagram code (https://sequencediagram.org/) participant

Energy application #lightblue

participant Energy digital entity #pink participant GIFT twin #pink participant Energy system #lightgreen

	group #pink inner interoperability GIFT twin<-Energy digital entity: Request end group #lightgreen outer interoperability note over Energy system, Energy digital entity: Observation end group #pink inner interoperability GIFT twin-> Energy digital entity: Information end group #lightblue transversal interoperability note over Energy digital entity: Monitoring, learning,\nreasoning note over Energy digital entity, Energy application: Inter- action (dashboard) end group #pink inner interoperability GIFT twin <-Energy digital entity: Control end group #lightgreen out- er interoperability note over Energy system, GIFT twin: Control end
IoT and edge infra-structure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** Digital twin are utilised to monitor and assist energy systems through the assistance of sensors to enable data capturing, sharing, processing and analysis and then enable flexibility and decarbonization of energy systems. Integration of smart meters, substations sensors with data space capability integrating AI, IoT and cloud solutions are foreseen.

Data space infra-structure	**Can you describe the data space infrastructure that your digital twins would like to use?** The GIFT infrastructure includes a complex configuration of Battery, sensors, smart meters and EMS. Management capabilities are included in the infrastructure as shown in Figure 33:  **Figure 33 – GIFT solution ecosystem**
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** We have identified the need for security and privacy capabilities at those levels: - Energy system - Prosumers - Digital twin - Energy digital unit

<table>
<tr>
<td>Other aspects</td>
<td>

Are there other aspects that you would like to report?

Figure 34 shows what could a generic conceptual model for an island grid digital twin.

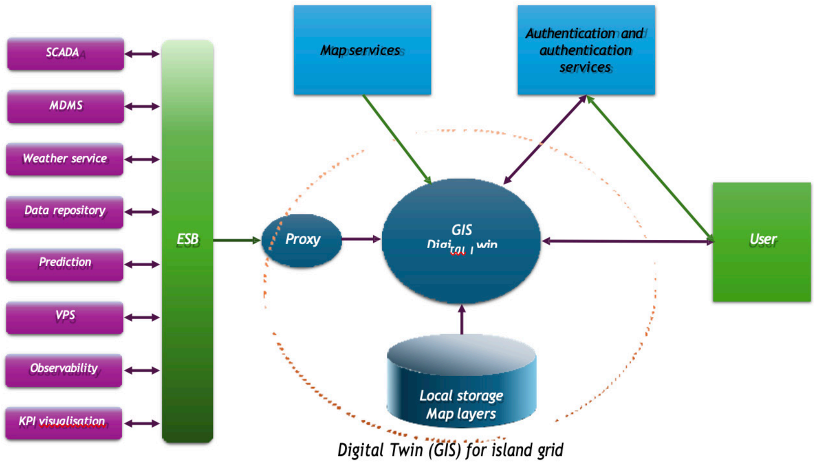


Figure 34 – Resulting conceptual model for Island grid digital twins

</td>
</tr>
<tr>
<td>References</td>
<td>

Provide references (e.g. URL)

Geographical Islands Flexibility (gift-h2020.eu)

</td>
</tr>
</table>

3.8 Energy digital twin – ENERSHARE

Table 12 – ENERSHARE

ENERSHARE - European common energy dataspace framework enabling data sharing-driven across- and beyond- energy services	
Contact	**Provide a contact point** Leonardo Carreras, RWTH-Aachen, leonardo.carreras@eonerc.rwth-aachen.de
Abbreviations	**List abbreviations used in your contribution** - O&M operation and management - SGAM smart grid architecture model - IDSA International data space association - DT digital twin

Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?**
	The ongoing energy system digitization is making available an enormous amount of data, paving the way for data sharing-enabled cross value chain services, which may contribute to system-level increased efficiency and hence facilitate the energy transition. However, data sharing in the energy sector is lagging behind, mainly due to lack of trust, privacy breaches risk and business models immaturity.
	In that respect ENERSHARE will
	- deliver a Reference Architecture for a European Energy Data Space, which hybridizes SGAM with IDSA and GAIA-X architectures, by bringing data value chain perspective into the energy one
	- evolve interoperability, trust, data value and governance building blocks to TRL 6-7 IDSA- compliant ones, adapt them to energy sector, and deploy:
	  - across-energy and cross-sector, data enhancement technology enablers and standardizable interfaces and open APIs by leveraging on open Standards (e.g. ETSI Context Broker) and ontologies (e.g. SAREF);
	  - trust-related connectors, to ensure privacy, confidentiality, cybersecurity preserving trust, sovereignty and full control of data;
	  - blockchain/smart contract-enriched marketplace for data versus energy assets/services coordination, sharing, exchange, and beyond financial compensation;
	  - cross-value chain value-added services and Digital Twins, by leveraging on privacy- preserving federated learning.
	- integrate and deploy them within a Reference Implementation of a European Energy Data Space, which will be demonstrated along 7 pilots and 11 intra-electricity, intra- energy and beyond energy use cases
	- co-design SSH-based consumer-centric business models for energy data sharing enabling data beyond-financial value creation and spreading along value chain
	- prepare the ground for the European Energy Data Space setup, through alignment with EU-level relevant initiatives (GAIA-X, IDSA, BDVA, ETIP SNET, BRIDGE), contributing to Data Space standardization and boosting a level playing field for data sharing
	The project started in July 2022 and will be completed in June 2025.

Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** There are three digital twins currently developed within the project: - Digital Twin for optimal data-driven Power-to-Gas optimal planning - Digital Twin based O&M algorithms and generation of synthetic failures data - Digital Twin for flexible energy networks Stakeholders: - Transmission System Operators - Distribution system operators - OEMs for wind turbine Aggregators Business expectations: - Gain insights for decision support concerning future P2G investments - Optimize the use of surplus renewable energy for green hydrogen production through electrolysis - Anomaly detection functions for the purpose of operation and maintenance Informed decision making for flexibility planning A description of each DT is listed below. **Digital Twin for optimal data-driven Power-to-Gas optimal planning** The platform TwinP2G integrates the national transmission and distribution networks of natural gas and electrical power managed by DESFA and IPTO, respectively. TwinP2G employs a DT architecture to enable multi-resolution simulations involving power-to-Gas (P2G) technologies and regenerative hydrogen fuel cells. The objective is to optimize the use of surplus renewable energy for green hydrogen production through electrolysis. Regarding the data sources to be considered in the DT, there are both national and European sources of historical energy data. These data sources (APIs and files) have different formats for each data type, requiring specialized processing. The simulation core of TwinP2G involves physics- and data-driven simulation and optimization. The main functionality of the "Simulation and optimization" component is the processing of historical time series of renewable generation, power and gas demands alongside forecasts produced by the "Forecasting" component. Based on these inputs it enables the study of local grid topologies in Greece, including P2G component investments, and using linear programming methods to cost optimize DTs that are modelled as electrical networks including buses, lines, links, generators and loads. The forecasting platform handles various time series data, integrates new datasets with ease, and provides forecasts of different time horizons (short-term, mid-term, long-term).

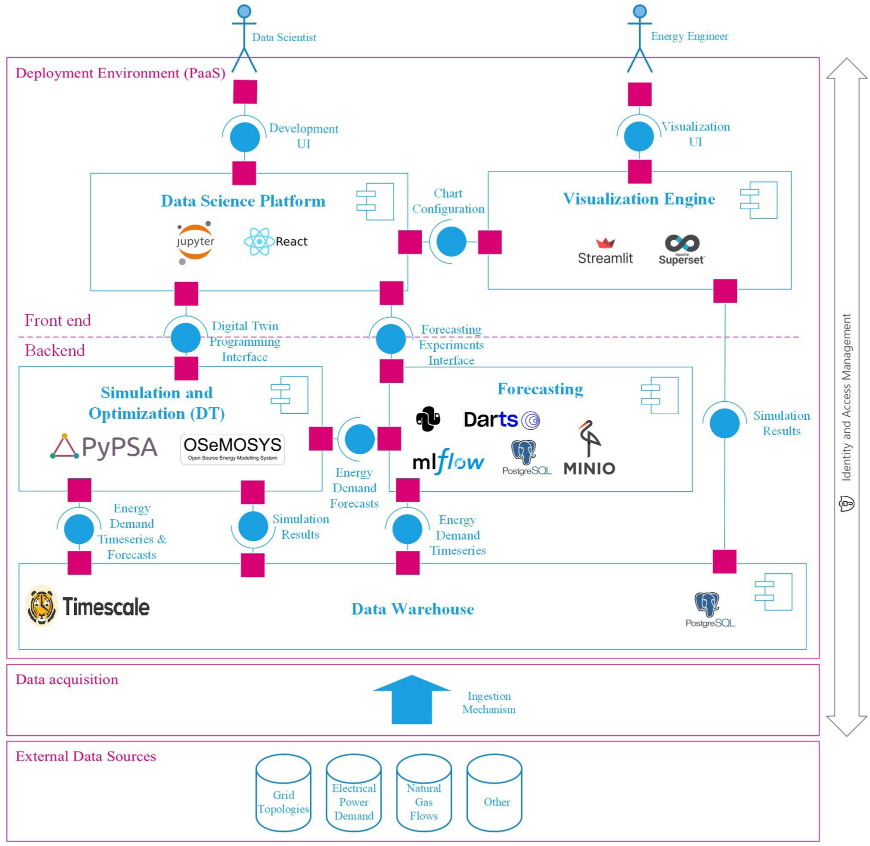


Figure 35 – High-level architecture of TwinP2G

Digital Twin based O&M algorithms and generation of synthetic failures data

The focus of this DT is on the improvement the O&M of wind turbines. For it, it will integrate anomaly detection functionality for the gearbox, electric generator and the hydraulic pitch system, based in simulation models.

A Simulink model, depicted in the Figure has been created (both for PMSG and hydraulic pitch system) to represent: electric failures such as short-circuits in the stator winding of the PMSG (inter-coil, phase- phase, ground-phase), as well as different working conditions in the hydraulic pitch system (pump condition ON/OFF, cylinder extension/retraction, ...).

To interact with the implementation, a microservice docker image is created by MATLAB® Compiler SDK™, providing an 1http/https endpoint to access MATLAB code, for running the Simulink model previously developed.

Digital Twin for flexible energy networks

The DT concept for electrical networks is based on the simulation tool DPSim and the acquisition of measurement points from a real electrical network. The idea behind is to replicate the behaviour of the network in real time settings, with the use of the most up-to-date status information that becomes available to make the calculations.

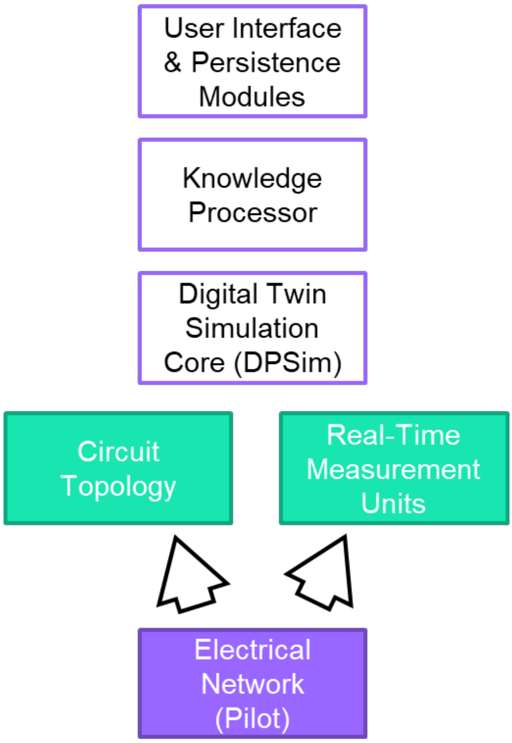


Figure 36 – High-level architecture of the DT for flexibility in electrical networks

The Circuit Topology is the representation of the electrical network in a level of abstraction that preserves and represent the behaviour of interest for the Use Case. This includes the connections, the individual components, the model representations to be assigned to them and the parametrization that is related to such model.

The Real-Time Measurement Units are the sensors that are part of the electrical network, with their data and communication links they provide the linkage to the reality with the data to update the values for the simulation and keeping the state of the DT in sync with the reality.

The DT Simulation Core is one of the key components of the simulation services that the DT provides. The inputs from the Circuit Topology and Real-Time Measurement Unit (when they are available) provide the necessary data to make the simulations. The set of voltages, currents, active and reactive powers can be provided upstream to be analysed and used to draw conclusions.

The Knowledge Processor is the other core component of the service. The goal is to give context to the information and help to have a more informed decision-making by providing insights to the human user. The expert human oversight will still be required, but a planning on how to allocate the resources/power available in the network or how to plan the best state for the network could be enabled by the technologies that use a hybrid approach based both on models and on novel techniques like data- driven, machine learning or artificial intelligence.

The last layer is the Frontend to the user, and it presents the information needed by each type of user, according to their expertise and generates reports that support the decision-making and the operation of the energy network.

Digital twin functions	**Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?** The following functions are used - At inception level, definition of energy goals and needs - At design level, digital twin system design, better understanding and analysis of data as well as physical entities - At deployment level, modelling and simulation better analysis of generated data and simulation results, better integration of control equipment, systems, environments, etc. - At operation and monitoring level, reduce operating costs, Prediction prognosis, Sustainability, Enhance user experience - At development and verification level, model training and improve simulation. - At retirement level, construction of historical database and scientific research. **Table 2 describes maturity dimensions. Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?** The following maturity levels are targeted: - Synchronized level for the convergence dimension - Predictive level for the capability dimension - Connected level for the integration dimension - Linked level for the time dimension
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) have been identified. Can you identify the interoperability needs of your digital twins?** Inner interoperability
IoT and edge infrastructure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** - Real Time Measurement Units , Smart Meters
Data space infrastructure	**Can you describe the data space infrastructure that your digital twins would like to use?** The Digital Twins will make use of IDS connectors and App Store components amongst other Building blocks of the data space infrastructure.
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** - Privacy when receiving data from OEMs and system operators
Other aspects	**Are there other aspects that you would like to report?** None
References	https://enershare.eu/resources/

3.9 Energy digital twin – TWIN-EU

Table 13 – TWIN-EU

TWIN-EU - Developing a concept of Pan-European Digital Twin of the electricity system	
Contact	**Provide a contact point** Ilias Zafeiropoulos *izafeiropoulos@ubitech.eu*
bbreviations	**List abbreviations used in your contribution** - DT digital twin
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** It is a key requirement for the European energy strategy to increase the penetration of renewables while aiming at making the grid infrastructure more resilient and cost-effective. In this context, digital twins (DT) can build a key asset to facilitate all aspects of business and operational coordination for system operators and market parties. TwinEU aims to develop a federated ecosystem of DT solutions that will valorize benefits of isolated instances, thus enable each operator to make its own implementation decisions while preserving and supporting interoperability and exchange with the remaining ecosystem. The project objective is to enable new technologies to foster an advanced concept of DT while determining the conditions for interoperability, data and model exchanges through standard interfaces and open APIs to external actors. The envisioned DT will develop the kernel of European data exchange supported by interfaces to the Energy Data Space under development. Building European Data Exchange Advanced modeling supported by AI tools and able to exploit High Performance Computing infrastructure will deliver an unprecedented capability to observe, test and activate a pan-European digital replica of the European energy infrastructure. Project developments and demonstrations encompass key players at every level from transmission to distribution and market operators, while also testing the coordinated cross-area data exchange. The project also includes relevant industry players, research institutions and associations with a clear record in developing innovative solutions for Europe. The project kicked off in January 2024 and will last 3 years. The pilot sites and use cases include; - The Iberian Peninsula Pilot: The focus of the Iberian Pilot is the security and resilience of the electricity system. For that, TwinEU will make use of a series of digital twins and a common framework for the interaction between them, oriented to enhance the security and resilience of the whole Iberian energy system, from generation, transmission, distribution, energy markets to final consumers. - The Eastern Mediterranean region pilot: Through the development of an integrated balancing market optimization model, the Demo aims at providing αctual and realistic scenarios for enabling the interconnection of digital twins between the mainland and Greece's main insular power system (Crete), as well as the islanded Cyprus power system.

- The Bulgarian pilot: The pilot foresees the evolution of the existing solutions into the next high Digital Density era, to offer adequate responses to resilience, proactivity and robust design. It will simultaneously allow the energy market actors located at the lowest voltage levels (consumers, prosumers, EV chargers, aggregators, energy communities or DERs) the non-discriminatory opportunity to participate in the process of providing the services necessary for the proper operation of the system.
- The German pilot: The current focus of this cooperation is on innovative assets and system control for TSO and DSO as well as an integrated multi voltage layer grid development and planning. The work of this demonstrator will build upon the activities both from the EU projects EU- SysFlex and eUniversal and the German project DesignNetz and include activities for: (i) Observability, Controllability & Real-Time Monitoring, (ii)Active System Management and forecasting to support flexibility and demand response, (iii)TSO-DSO interoperability, (iv) Efficient smart infrastructure and collaborative network planning, (v) Operations and simulations for a more resilient cybersecure smart grid, (vi) Increase potential to co-simulate and parallelize the proposed DT functionalities.
- The Italian pilot: The Italian pilot use cases address two areas, the Sardinia island where there are about 1 GW of wind power plants and 1 GW of photovoltaic plants in total, the Sardinian transmission grid is interconnected to the national and European grid through 2 HVDC links having a transmission capacity of about 1300 MW. In future scenarios, a strong development of additional wind and photovoltaic generation capacity is forecasted especially in South Italy, Sicily and Sardinia, therefore Terna has planned the realization of a new HVDC link (the Tyrrhenian Link, having a capacity of 1000 + 1000 MW) that will interconnect the three involved network portions. A DT-based defense system will be developed to study active system management and TSO/DSO interaction.
- The Slovenian pilot: The main objective of the demo is to upgrade the existing network operation and stability management process, which will be based on increased system observability (enhanced monitoring of the system) and controllability (services provided by PE-interfaced devices). The controllability enhancement will encompass the development of a new fast-frequency response service, which will increase the much-needed flexibility of the system and is seen as crucial for ensuring its resilient operation.
- The French/Dutch Pilot: integrated energy system, it is essential to develop digital twins that address two challenges: i) analysis, planning, and operation of cyber resilient transmission and distribution systems, and ii) knowledge utilization and building human capital for utilities using Control Room of the Future (CRoF) at TU Delft, RTE, RWTH and Fraunhofer to enable the provision of a joint, coordinated response from cyber security experts and transmission / distribution system operators to cyber-attacks using digital twins. This pilot aims at creating mutual benefits for TSO and DSO by providing a computationally efficient and numerically trustworthy tools for anticipating and preventing/mitigation instability phenomena under high penetration of RES and under weak network topological/operational conditions.

Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** The stakeholders of the TwinEU ecosystem are - Transmission System operators (TSOs), - Distribution System Operators (DSOs), - Market operators (MOs) - Energy producers & suppliers - Aggregators - Service providers - Regulatory entities/policy makers The federated DT ecosystem of TwinEU aims to bridge distributed digital twins instances and facilitate the seamless cooperation of all energy market entities, aiming at several business expectations, such as: - Define a set of scenarios for the use of digital twin that will benefit from data sharing and exchange among operators (intra and cross-country) and the corresponding requirements for implementation. - Define and implement a Reference Architecture for the creation of a European-scale Digital Twin. - Define and implement a federated digital twin, consisting of a variety of closed loop adaptive DT instances, to support European-level wider replication. - Enhance data models and semantic interoperability to better support the digital twin use cases. - Leverage on and adapt the emerging concept of energy data space to break data silos across energy value chain stakeholders, facilitate trusted and sovereignty-preserving data, model and computational resource cross-stakeholder sharing. - Leverage advanced technologies such as physics-informed AI and High-Performance Computing to go beyond classical modelling approaches for digital twin. - Develop and deploy a variety of DTs services which will create the conditions for a more resilient and reliable European power network. (- Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains. - Large adoption of the TwinEU approach creating the condition for a real implementation at European scale. - Creating the conditions for the long-term sustainability development of the TwinEU vision and open new business opportunities based on DT.
Digital twin functions	**Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?** **Table 2 describes maturity dimensions in Table 2). Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?** The project is still in the initial stages and the details for the functional view of the DTs are not currently finalised.
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) have been identified. Can you identify the interoperability needs of your digital twins?** The project is still in the initial stages and the details for the functional view of the DTs are not currently finalised.

IoT and edge infrastructure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** The TwinEU will develop an Adaptive Twins (AT) federation layer responsible for the creation of interoperable interfaces supporting exactly the bidirectional data flow operations among physical and virtual entity, integrating through the project OneNet and project ENERSHARE connectors a series of IoT/edge computational/edge nodes which exploit Data Sources & Devices. It forms the basis of the European Digital Twins but also the first step in creating an integrated data value chain from the physical layer to the federation/orchestration of data assets to specific grid service/applications. In other words, this layer is representing the virtual distribution of all participating ICT components including Data Hubs/Lakes, other ICT resources (such as high- performance computing resources, data storage/persistency resources, virtualized Meters and Actuators, UAVs, digitized assets, such as substations, PV farms, etc.), which will feed the pan- European Data Orchestrator/Federator. This layer will be in charge of managing different types of data assets, including data sets and/or data models, including 3D/geographical models, which consume datasets to refine and improve the model itself.
Data space infrastructure	**Can you describe the data space infrastructure that your digital twins would like to use?** The intentions of the TwinEU project is to propose a dataspace-enabled data/models sharing infrastructure. This will consist of the energy Data Space adaptation to the context of the TwinEU Digital Twin and will enable the trusted sovereignty-preserving Data/Model sharing layer, which includes: - mirroring real Extended interoperability management based on a MIM (Minimum Interoperability Mechanism) approach, which includes tools for enriching the Shared Vocabulary to capture some new aspects and features of the grid assets. Here adaptation of SAREF4ENER (leveraging from the H2020 InterConnect semantic interoperability framework), SARGON ontology, IEC family of standards will be carried out. - usage Control, data usage traceability for sovereignty-preserving data sharing “as and when needed” to increase reciprocal trust among data providers and data consumers.
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** The project is still in the initial stages and the details for the security and privacy capabilities of the DTs are not currently finalised.
Other aspects	**Are there other aspects that you would like to report?** Not at this point
References	https://twineu.net/

3.10 Energy digital twin – Wind Farm Remote Operations Center

Table 14 – Wind Farm Remote Operations Center

Wind Farm Remote Operations Center	
Contact	Gavin Green, VP Strategic Solutions, XMPro
Abbreviations	**List abbreviations used in your contribution** None
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** This is a "technology showcase" of the Digital Twin Consortium, developed and documented by XMPro. The objective is to provide remote real-time monitoring, control, and optimization of wind turbines and associated systems, to increase energy production, reduce downtime, and enhance safety and maintenance efficiency.
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** A digital twin remote operations center enables remote monitoring, control, and management of complex systems, such as wind farms, without requiring on-site personnel.
Digital twin functions	**Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?** A composable digital twin enables integration of various capabilities to create a comprehensive virtual representation of the physical system. The modular nature of the composable digital twin allows easy integration of new technologies and upgrades, while enabling remote decision-making for operational planning and actions. The digital twin provides a virtual representation of the wind farm synchronized at a high frequency and fidelity. This enables real-time monitoring, analysis, and optimization. By integrating data from sensors and historical performance, the digital twin can predict the wind farm's behavior and identify potential issues before they occur. From there, proactive measures can be taken.
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?** Provides an intuitive remote operations center interface with 3D models, GIS maps, and customizable dashboards.
IoT and edge infrastructure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** Sensors collect real-time data streams (signals) from the field from wind turbines and equipment using IoT devices, sensors, and communication protocols. The solution Includes an option to implement edge computing for initial data processing and filtering.

Data space infra-structure	**Can you describe the data space infrastructure that your digital twins would like to use?** The visual representation for remote operators displays real-time data and key performance indicators. The digital twin model is based on IEC 61400-25 (DTDL in the Digital Twin Consortium Github).
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** Not addressed
Other aspects	**Are there other aspects that you would like to report?** The system provides real-time recommendations for predictive maintenance, performance optimization, anomaly detection, and decision support, leveraging advanced analytics, machine learning, and AI techniques.
References	**Provide references (e.g. URL)** - *Wind Farms Remote Operations Center - Digital Twin Consortium* (includes a link to a webinar)

3.11 Smart manufacturing – Manufacturing Quality Control Via Remote Operator

Table 15 – Smart manufacturing – Manufacturing Quality Control Via Remote Operator

Manufacturing Quality Control Via Remote Operator	
Contact	Dr. Ander García, Lead of Connectivity and Cloud/Edge Computing Research Line, Vicomtech
Abbreviations	**List abbreviations used in your contribution** - AAS: Asset Administration Shell - ERP: Enterprise Resource Planning - HPC: High-performance computer - MES: Manufacturing Execution System
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it complete?** This is a "technology showcase" of the Digital Twin Consortium, developed and documented by Spanish organizations Vicomtech and Aingura IIOT. The goal of the project is to increase the flexibility of manufacturing lines to adapt them to today's remote inspection scenarios. This prevents stopping production when an operator is remotely located. It introduces digital twins into the legacy manufacturing process, to bring it into alignment with post- Covid remote personnel requirements.
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** A digital twin of a manufacturing cell enables manipulation and quality control inspection of manufacturing cells using Virtual Reality.
Digital twin functions	**Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?** The digital twin provides a digital replica of the manufacturing cell, enabling manipulation and quality control inspection using Virtual Reality (Oculus VR). It also tracks energy efficiency, performance metrics, and maintainability of the manufacturing line.
Interoperability	**Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?** The digital twin is integrated with the Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES).
IoT and edge infrastructure	**Can you describe the IoT and edge infrastructure that your digital twins would like to use?** A Data Acquisition Module communicates with the elements of the manufacturing line to store relevant traceability and process data on a High-Performance Computer (HPC).
Data space infrastructure	**Can you describe the data space infrastructure that your digital twins would like to use?** This data feeds an Assets Administration Shell (AAS)-based digital representation of the line elements that are the input for the twin.

Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** Not addressed
Other aspects	**Are there other aspects that you would like to report?** No other aspects to report
References	**Provide references (e.g. URL)** - *Manufacturing Quality Control Via Remote Operator* (includes a link to a webinar)

3.12 Smart Manufacturing – Circular TwAIn

Table 16 – Smart Manufacturing – Circular TwAIn

<table>
<tr><th colspan="2">Circular TwAIn – Digital Twin with AI functionality for Circular Manufacturing</th></tr>
<tr><td>Contact</td><td>An Lam, SINTEF, Arne J. Berre, SINTEF</td></tr>
<tr><td>Abbreviations</td><td>List abbreviations used in your contribution
- AAS: Asset Administration Shell
- EDC: ECLIPSE Dataspace Connector</td></tr>
<tr><td>Digital twins</td><td>Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)
The Digital Twins (with AI support) are connected through an approach defined by the industrial digital twin association, based on the AAS (Asset Administration Shell) approach.


Figure 37 – AAS specifications
AAS Specifications define the software structure, interface and semantics of the Asset Administration Shell and thus create the basis for the standardized Digital Twin. All specifications for the Asset Administration Shell information model can be found here.
As it can be seen, the AAS specification is currently structured into five parts:
- Part I is about the AAS metamodel and serialization formats (JSON, XML and RDF)
- Part II specifies the APIs for reactive AASs, which are executable AAS that can be communicated with via APIs
- Part III specifies data specification templates conformant to IEC 61360 which defines the semantics of single properties or values
- Part IV covers the AAS security metamodel
- Part V defines the AASX Package Exchange Format (AASX) to be used as the exchange file format for the transport of information from one partner in the value chain to the next.
All parts of the AAS specification except part IV are already available for download.
We note here that the AAS implementations used in the Circular TwAIn Project (as well as the other open source implementations of AAS) focus only on Part I and Part II.</td></tr>
</table>

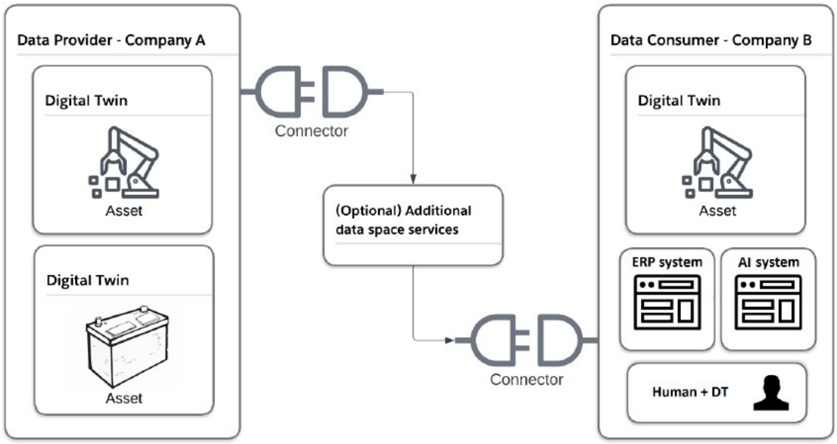


Figure 38 – Combination of Digital Twins and Data Spaces (simplified)

A dataspace is both a multi-organizational agreement and a supporting technical infrastructure that enables data sharing between two or more participants. Participants in a dataspace can have a variety of pre-existing levels of trust. Some might have a previous relationship and trust each other, while others might not have any relationship at all and be untrusted entities. Dataspaces even enable data sharing among direct competitors. It provides answers for technology challenges of data sharing:

- How do I find data?
- How do I publish my data in a secure way?
- How do I share my data in a multi-cloud environment
- How do I maintain control over my dta once it has been shared?

Since the concept of dataspaces is emerging and promise new capabilities to the data exchange between dataspaces' participants in terms of data sovereignty, we need technical components that implement the concepts.

The Eclipse Dataspace Components (EDC) is a comprehensive framework (concept, architecture, code, samples) providing a basic set of features (functional and non-functional) that dataspace implementations can re-use and customize by leveraging the framework's defined APIs and ensure interoperability by design. It is powered by the specifications of the Gaia-X AISBL Trust Framework and the IDSA Dataspace protocol.

The EDC is designed for developers who want to build dataspace implementations on an existing, standards-based framework and adopt and adapt it with their own solutions: Developers use the EDC to build data-sharing services for their customers.

The framework consists of a set of components and corresponding capabilities that are mandatory to implement a dataspace:

- Connector
- Federated Catalogue
- Identity Hub
- Registration Service
- Data Dashboard (Management UI)

The EDC project also provides repositories to support the onboarding of developers with simplified, essential examples.

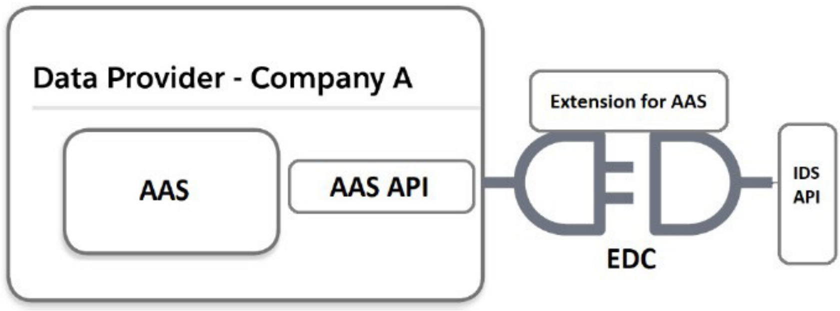


Figure 39 – Extension for AAS

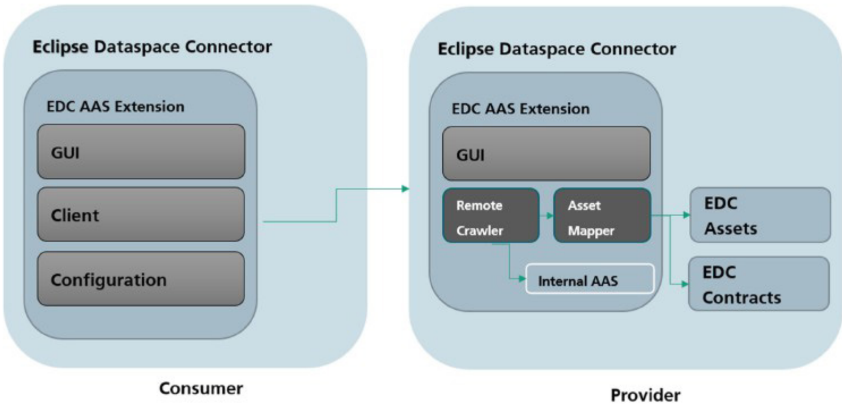
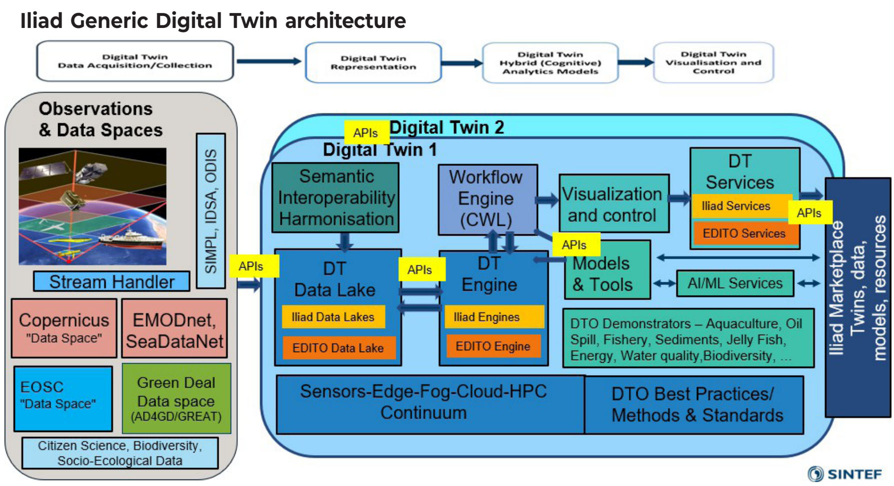


Figure 40 – ECLIPSE Dataspace Connector

References	**Provide references (e.g. URL)** Circular TwAIn: https://www.circular-twain-project.eu/ IDTA: https://industrialdigitaltwin.org/ AAS: Details Of the Administration Shell - Part 1 (industrialdigitaltwin.org) IDSA: https://internationaldataspaces.org/ EDC: https://projects.eclipse.org/projects/technology.edc

3.13 Environmental Digital Twins – Iliad Digital Twins of the Ocean

Table 17 – Environmental Digital Twins – Iliad Digital Twins of the Ocean

Iliad Digital Twins of the Ocean	
Contact	Babis, Netcompany, Dr. Arne J. Berre, SINTEF
Abbreviations	**List abbreviations used in your contribution** - DTO: Digital Twins Ocean - DestinE – Destination Earth
Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)** The following describes a set of Environmental digital twin architectures – starting with the Iliad project – and then also showing the architectures from the Destination Earth project and the EDITO-Infra project and explains their interoperability relationships.  **Figure 41 - Iliad Digital Twins connected to Data Spaces**

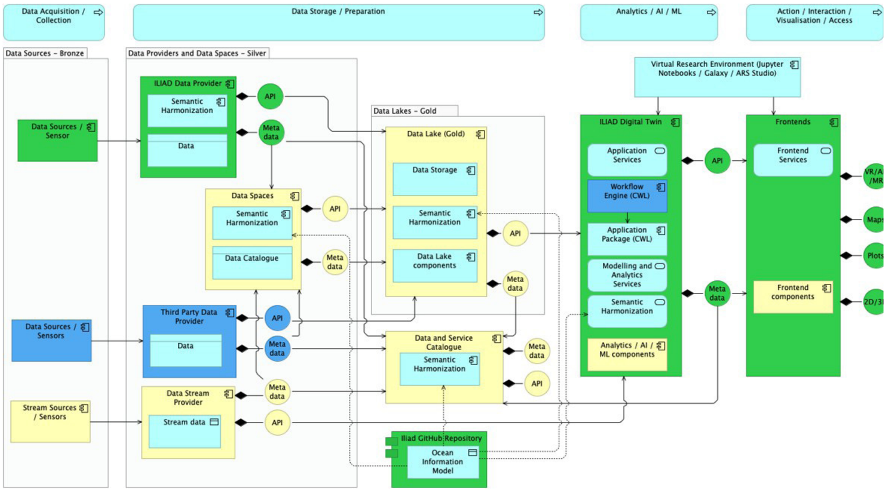


Figure 42 - Iliad Digital Twins architecture in ArchiMate

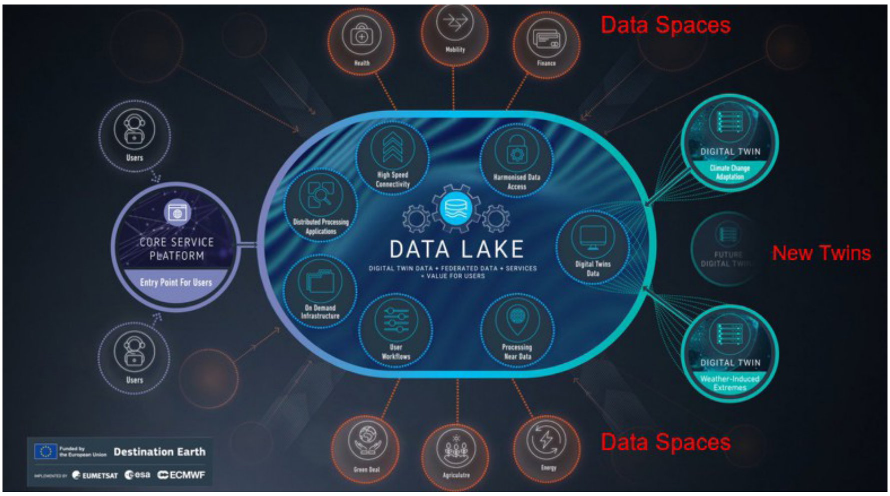


Figure 43 - Destination Earth Digital Twin architecture with Data Spaces and Data Lake

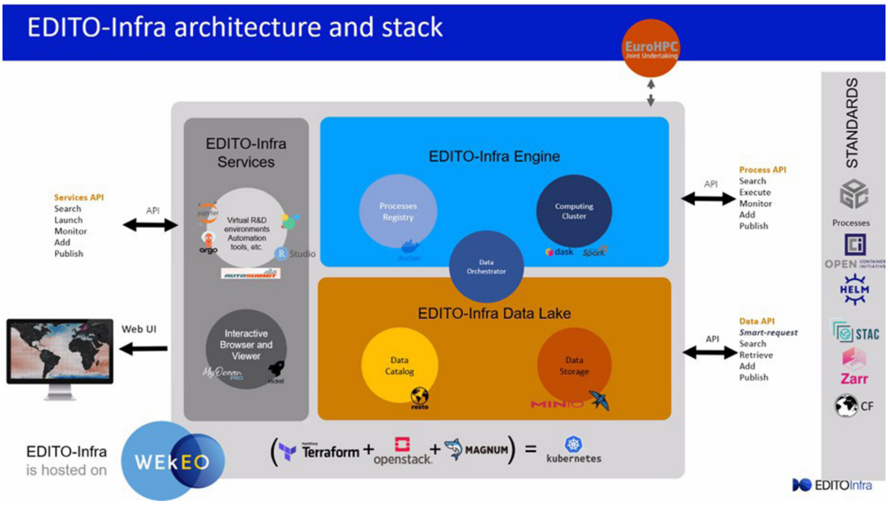


Figure 44 - EDITO-Infra conceptual architecture

The EDITO Infra conceptual architecture is showing the user interaction to the left and the input from data sources to the right. The EDITO-Infra service platform is supporting virtual R&D environments and tools, such as Jupyter notebooks and R Studio. Workflow orchestration is being supported through Autosubmit which is deriving from HPC workflow support. The EDITO Data Lake provides initially MinIO S3 compatible bucket storage and in particular support for STAC (Spatio Temporal Asset Catalogue) with associated STAC APIs and data representations in the forms of Zarr and NetCDF CF. The EDITO-Infra digital twin Engine is supporting cloud computing clusters with container-based technologies (Open Container initiative) and solutions with Docker and Kubernetes and distributed processing with Dask, HELM and Spark.

Within the EU DTO family of projects, the Iliad architecture is being harmonised with the EDITO Infra project to ensure interoperability with EDITO-Infra and EDITO-Modellab.

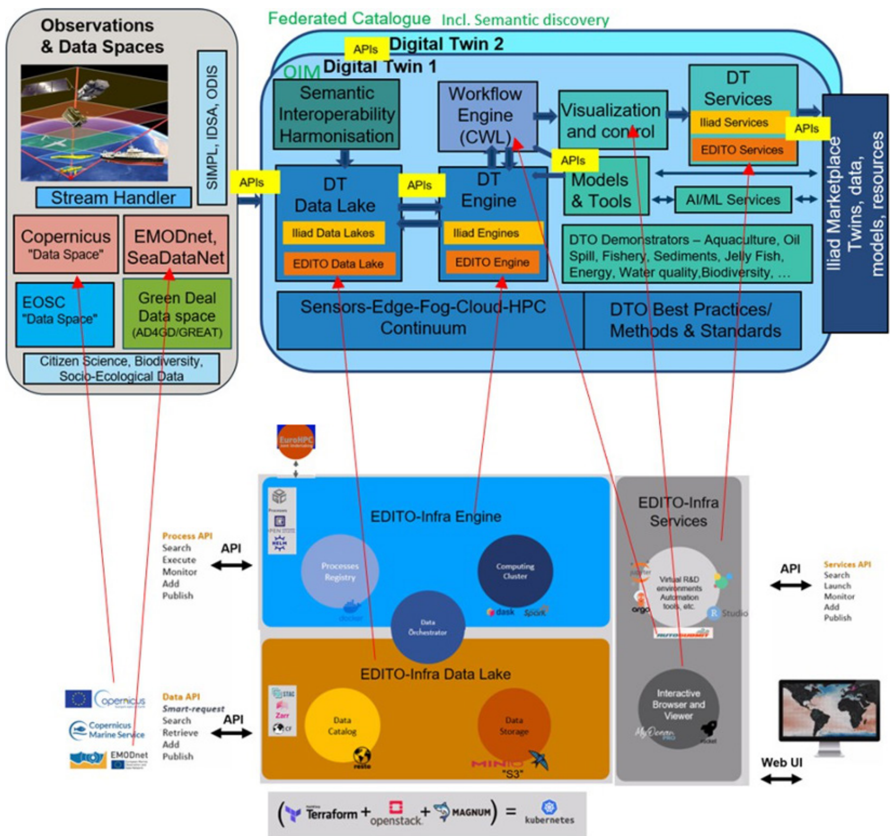


Figure 45 - Interoperability of the Iliad and EDITO architectures

In figure above the EDITO architecture is turned around to show the EDITO alignment with the digital twin pipeline steps with data flowing from left to right to better illustrate the interoperability areas. The main EDITO architectural components follows the structure of the Destination Earth (DestinE) digital twin architecture with a Data Lake, a Digital Twin Engine, and a Service platform. The focus of data representations in the Data Lake is on Analysis Ready Cloud Optimised (ARCO) data with a basis in STAC (Spatio Temporal Asset Catalogue) and use of data formats like Zarr and Parquet.

The Iliad architecture aims to be interoperable with the EDITO architecture and supports the possibility for Digital Twins to be related to and use the EDITO Data Lake, Engine and Services. It is also possible to follow this architecture with alternative physical data lakes, engines and service environments – as many local and domain specific digital twins then can take advantage of other storage and computational resources.

Iliad is further addressing the interoperability with the emerging European Data Spaces. In particular, with Iliad being part of the European Green Deal project portfolio, there is a focus on how to support and use the forthcoming European Data Spaces in general and on the Green Deal data space in particular. The area of digital twin real world observations in particular through various sensor types and citizen science is also focused on in Iliad, while these areas are left out of focus in the EDITO-Infra project.

The starting point of data access APIs in the Iliad projects has been related to the use of the OGC Open APIs and in particular through the set of OGC supported standards available in Python through pygeoapi. In line with the selected focus

<table>
<tr><td></td><td>on the use of the STAC implementation in both Destination Earth and EDITO, OGC is now also including the STAC – Spatial Temporal Asset Catalogue – into the pygeoapi support.</td></tr>
<tr><td></td><td>

Data lake in Destination Earth project

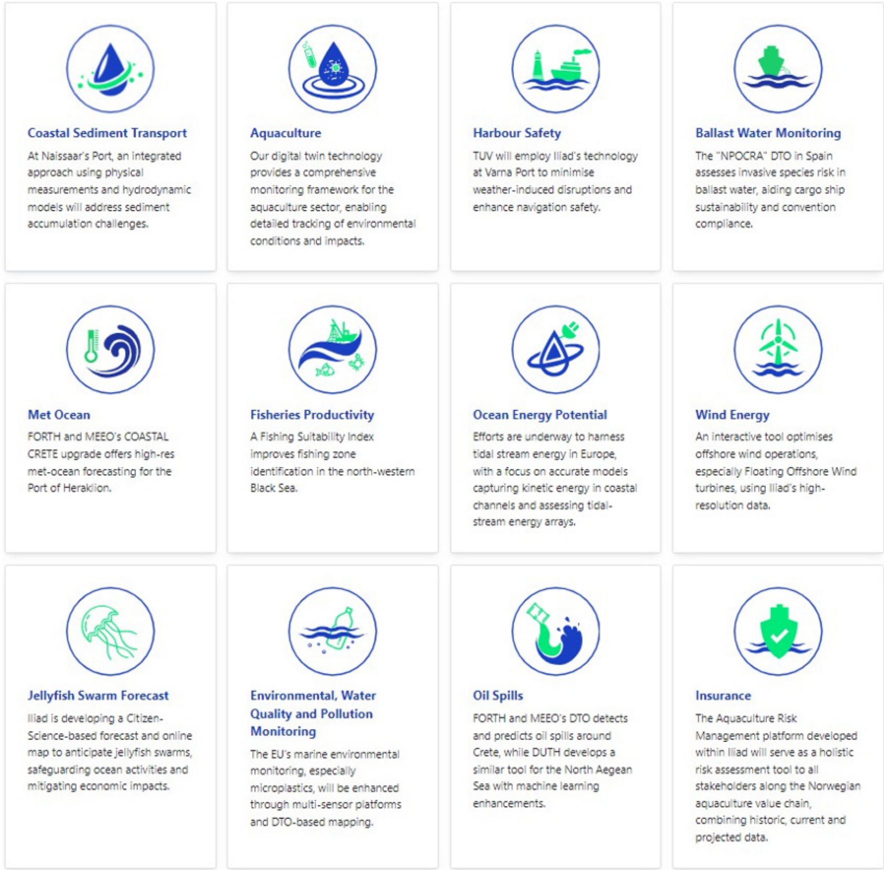


Figure 46 – Iliad 12 different groups of digital twins

The Iliad project is supporting 22 different local and sector specific Digital Twins of the Ocean in 12 different groups of digital twins.</td></tr>
<tr><td>Digital twin functions</td><td>

Table 1 identifies digital twin functions. Which ones have you used? Which ones do you plan to use? Do you have suggestions about additional functions?

The digital twin provides a digital replica of the manufacturing cell, enabling manipulation and quality control inspection using Virtual Reality (Oculus VR). It also tracks energy efficiency, performance metrics, and maintainability of the manufacturing line.</td></tr>
<tr><td>Interopera-bility</td><td>

Three types of interoperability (inner interoperability, outer interoperability and transversal interoperability) are identified. Can you identify the interoperability needs of your digital twins?

In the family of Digital Twins of the Ocean there is a need for many types of inter-operability,</td></tr>
<tr><td>IoT and edge infrastructure</td><td>

Can you describe the IoT and edge infrastructure that your digital twins would like to use?

A Data Acquisition Module communicates with the elements of the manufac-turing line to store relevant traceability and process data on a High-Performance Computer (HPC).</td></tr>
</table>

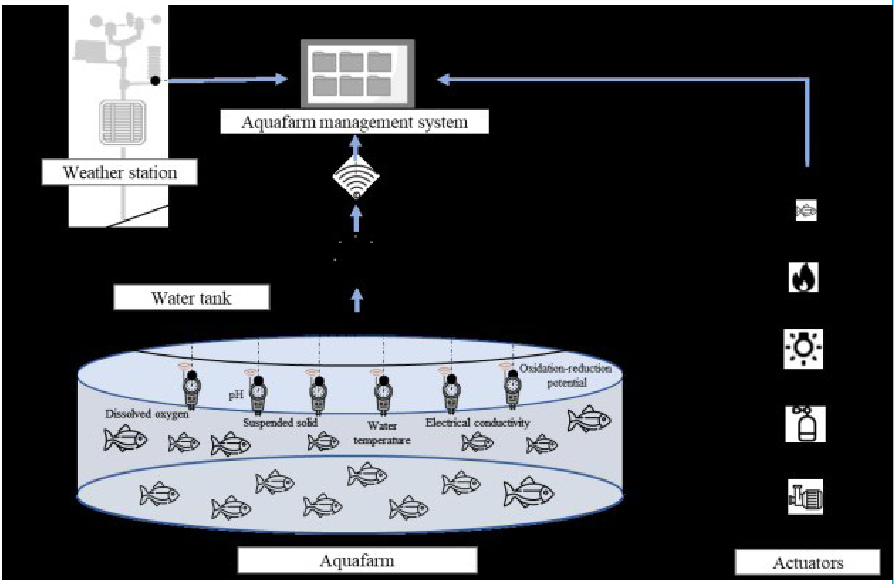
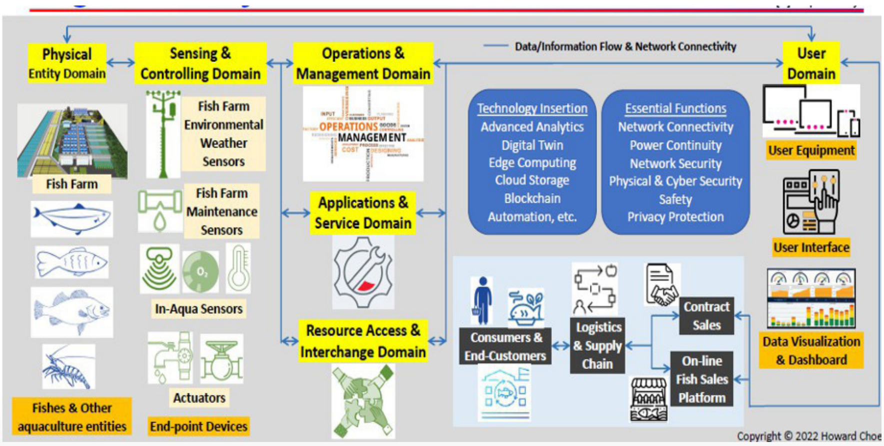
Data space infrastructure	**Can you describe the data space infrastructure that your digital twins would like to use?** This data feeds an Assets
Security and privacy	**Can you describe security and privacy capabilities that your digital twin would like to use?** Not addressed
Other aspects	**Are there other aspects that you would like to report?** No other aspects to report
References	**Provide references (e.g. URL)** - Iliad DTO: *https://ocean-twin.eu/* - Destination Earth Digital Twins: *https://destination-earth.eu/* - Ocean – DITTO: *https://ditto-oceandecade.org/* - Ocean – EDITO: *https://www.edito.eu/*

1.1 Ocean – AquaInfra

Table 18 – Smart Aquaculture – smart monitoring service of environmental conditions

Smart Aquaculture – smart monitoring service of environmental conditions	
Contact	Asbjørn Hovstø, NEK/SC41, ahovsto@gmail.com
Abbreviations	**List abbreviations used in your contribution** The ITU-T Recommendations use the following terms defined elsewhere: **Access network** [ITU-T Q.1742.1]: A network that connects access technologies (such as a radio access network) to the core network. **Application** [ITU-T Y.2091]: A structured set of capabilities, which provide value-added functionality supported by one or more services, which may be supported by an API interface. **Context** [ITU-T Y.2002]: The information that can be used to characterize the environment of a user. **Core network** [ITU-T Y.101]: A portion of the delivery system composed of networks, systems equipment and infrastructures, connecting the service providers to the access network. **Device** [ITU-T Y.4000]: With regard to the Internet of Things, this is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, date capture, data storage and data processing. **Gateway** [ITU-T Y.4101]: A unit in the Internet of Things, which interconnects the devices with the communication networks. It performs the necessary translation between the protocols used in the communication networks and those used by devices. **Internet of Things** [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies. NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled. NOTE 2 – In a broad perspective, the IoT can be perceived as a vision with technological and societal implications. **IoT area network** [ITU-T Y.4113]: A network of devices for the IoT and gateways interconnected through local connections. **Object** [ITU-T Y.2002]: An intrinsic representation of an entity that is described at an appropriate level of abstraction in terms of its attributes and functions. **Sensor** [ITU-T Y.4113]: An electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic. **Sensor node** [ITU-T Y.4105]: A device consisting of sensor(s) and optional actuator(s) with capabilities of sensed data processing and networking. **Smart Farming based on networks** [ITU-T Y.4450]: A service that uses networks to actualize a convergence service in the agricultural field to attain more efficiency and quality improvement and to cope with various problems. **Thing** [ITU-T Y.4000]: In the Internet of Things, this is an object of the physical world (physical things) or of the information world (virtual things), which is capable of being identified and integrated into the communication networks.

	Ubiquitous networking [ITU-T Y.4450]: The ability for persons and/or devices to access services and communicate while minimizing technical restrictions regarding where, when and how these services are accessed, in the context of the service(s) subscribed to. **3.2.1 Smart Livestock Farming:** A convergence service which applies Information and Communication Technologies (ICT) into livestock value chain, with potential to deliver a more productive and sustainable production. NOTE 1 – By integrating processes of the smart farming, management information systems, stockbreeding automation and robotics, smart livestock farming helps decision making for more effective and efficient exploitation, operations and management of livestock value chains. NOTE 2 – Examples of products from domesticated animals (not as a pet) through livestock are fish, meat, eggs, milk, honey, fur, leather, and wool.
Description	**Describe the project (objectives, use cases or pilots). Is the project completed? When does it completes?** Fish farming referred to as aquaculture has also made technical progress with the development of ICTs. However, it is not well organized by comparing with the agriculture and livestock industry. An IoT sensor that can monitor the environmental conditions of fish growing must be installed in a smart aquaculture. Automatic monitoring of the environmental conditions uses IoT devices such as sensors and monitored data transfer to a controller to activate actuators that adjust the environmental conditions in smart aquaculture. This use case describes the way of automatically monitoring the dissolved oxygen (DO), air and water temperature, pH, humidity, carbon dioxide (CO2), electrical conductivity (EC), suspended solid (SS), turbidity, oxidation-reduction potential (ORP), total ammonia nitrogen, and water levels in the smart aquaculture for fish growth. The initial cost to install IoT and AI-assisted smart aquaculture systems would be very high. But it is beneficial after the first installation by reducing the loss of fish and energy consumption. Figure 47 shows the overview of the configuration to monitor various environmental parameters (e.g., dissolved oxygen, pH, suspended solids (SS), water temperature, electrical conductivity, etc.). The gathered information is stored in the database (aquafarm management system) and used for automatic control, analysis, and simulation. The measured information using IoT devices includes the type of sensor device and the measurement value.

Digital twins	**Describe the digital twins of the project and their purpose (stakeholders, business expectations, digital twin characteristics)**  **Figure 47 - Aquaform digital twin** Overview of the configuration to monitor various environmental parameters and actuator operation information in smart aquaculture.
Digital twin functions	**Can you position the maturity level reached (or to be reached) by your digital twins? Do you have suggestions about other maturity dimensions?** After gathering and analysing environmental conditions to grow fish in smart aquaculture, fish productivity can be improved using an automatic control system by optimizing the types and levels of various components, which are included in water quality.  **Figure 48 - Aquaform high-level architecture**

Other aspects	**Are there other aspects that you would like to report?** Potential standardization areas are - General requirements and specifications, - Reference architecture, - Fish farm monitoring – fish health, water condition, maintenance, environment, etc. - Fish farm automation – intelligent feeding, biomass determination, etc. - Fish farm sensing requirements and technologies - Fish farm surrounding development - Different types of applications and services with fish farming, - Fish farming business model.
References	**Provide references (e.g. URL)** - https://www.the-iot-marketplace.com/solutions/fish-farming - https://futureeuaqua.eu/index.php/2021/02/24/how-can-the-internet-of-things-iot-enhance-fish-health-and-welfare/ - https://www.globenewswire.com/news-release/2021/01/13/2158043/0/en/Global-Fish-Farming-Market-to-Reach-376-48-billion-by-2025-AMR.html - https://www.asc-aqua.org/programme-improvements/aligned-standard/asc-farm-standard-principle-1/ - https://www.iso.org/committee/541071.html - https://www.asc-aqua.org - The clipart icons used in Charts #2 and #7 in this presentation are from Google image search, freedownload, free trial, etc., from various clipart websites or other websites and from Dr. Jie Shen's "Studyon the Integration IoT & Blockchain," May 2018. https://www.iso.org/committee/541071/x/catalogue/p/1/u/0/w/0/d/0 - https://www.gs1.org/sites/default/files/docs/traceability/GS1_Foundation_for_Fish_Seafood_Aquaculture_Traceability_Guideline.pdf

4. Further planned use case contributions

The following projects will be considered for the final version of this document

- Transport (Marine)
  - Vessel-AI
- Smart Manufacturing
  - COGNITWIN
  - ACCURATE
  - COGNIMAN
  - Change2Twin
- BimProve
- Smart City Local Digital Twin Toolbox
  - Energy digital twin
- TWIN-EU
  - Environmental Digital Twins
  - Earth - Destination Earth Twins (Climate and Extreme Weather Digital Twins)
  - Earth – BioDT
  - Earth – InterTwin and EOSC (Data Space)
  - Ocean – DITTO
  - Ocean – EDITO-Infra and EDITO-ModelLab
  - Ocean – Blue Cloud
  - Ocean – DTO-BioFlow
- Ocean – SEADITO

5. Conclusions and recommendations for standardisation

In the first report of AIOTI on the integration of IoT and Edge computing in data spaces[14] that was published in 2022, the following recommendations were made

- R1: agree on data space principles.
- R2: work on data space standards following an architecture of standard,

R3: integrate IoT, Edge and digital twin concerns in data space standards.

R1 is currently addressed with the work done in ISO/IEC JTC 1/SC 38 with ISO/IEC 20151 (Dataspace concepts and characteristics) as well as in ISO/IEC JTC 1/SC 41 on ISO/IEC PWI JTC1- PWI17 (Integration of IoT and digital twin in data spaces).

This document addresses R2 and R3 by providing:

- a wide variety of digital twin use cases in various domains,
- examples of architecture patterns to describe the process of extracting data
- the variety and complexity of needs.

This report has two additional recommendation:

- R4: create a repository of architecture patterns which capture the different IoT and digital twin approaches to be connected to data spaces.
- R5: interoperability support, based on international standards, is needed for cross-border data flows, between EU and other markets outside Europe, e.g., EU-USA, EU-Japan, EU- China.

1

14 https://aioti.eu/wp-content/uploads/2022/09/AIOTI-Guidance-for-IoT-Integration-in-Data-Spaces-Final.pdf

6. Contributors

Editors:
Antonio Kung (Trialog)
Arne J. Berre (SINTEF)

Reviewer:
Damir Filipovic (AIOTI)

Contributors:
1. Arne Berre (SINTEF)
2. Asbjørn Hovstø (Hafenstrom)
3. Claude Baudoin (DTC)
4. Daniel Alonso (BDVA)
5. Detlef Tenhagen (Harting)
6. Eduardo Loscos (WWW)
7. Georgios Karagiannis (Huawei)
8. Giuseppe Ciulla (Engineering)
9. Jeroen Broekhuijsen (TNO)
10. Jishan Li (China Southern Power grid)
11. Karim Tobich (CyberSecurity and Technology consultancy)
12. Kim Yan (Cisco)
13. Leonardo Carreras Rodriguez (RWTH - Aachen)
14. Lizhen Huang (NTNU)
15. Monica Florea (Simavi)
16. Roberto Di Bernardo (Engineering)

7. Acknowledgements

8. About AIOTI, BDVA, StandICT, HS Booster

AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT and Edge Computing Innovation in Europe, bringing together small and large companies, academia, policy makers and end-users and representatives of society in an end-to-end approach. We work with partners in a global context. We strive to leverage, share and promote best practices in the IoT and Edge Computing ecosystems, be a one-stop point of information on all relevant aspects of IoT Innovation to its members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of IoT and Edge Computing Innovation in society. AIOTI's contribution goes beyond technology and addresses horizontal elements across application domains, such as matchmaking and stimulating cooperation in IoT and Edge Computing ecosystems, creating joint research roadmaps, driving convergence of standards and interoperability and defining policies.

BDVA

BDVA is an industry-driven research and innovation organisation with a mission to develop an innovation ecosystem that enables the data-driven and AI-enabled digital transformation of the economy and society in Europe.

We help advance and promote areas such as big data technologies and services, data platforms and data spaces, Industrial AI, data-driven value creation, standardisation and skills.

StandICT

StandICT.eu 2026 builds on the success of the previous two editions [2020-23 & 2018-19 StandICT.eu initiatives], obtaining the recognition of the "go-to" project on ICT Standards in Europe. StandICT.eu 2026's principal goal is to strengthen its global reach in the European ICT Standardisation Ecosystem

HSBooster

HSbooster.eu is a 30-month European Commission initiative that will provide the European Standardisation Booster. The booster provides expert services to European projects to help them to increase and valorise project results by contributing to the creation or revision of standards.

HSbooster.eu facilitates and streamlines the dialogue between Horizon 2020 and Horizon Europe Research & Innovation projects with the Standardisation landscape and its main actors, namely corresponding Standards Developing Organisations (SDOs) to increase the European impact on (international) Standardisation and strengthen the European competitiveness.

The StandICT.eu 2026 project is funded by the
European Union under grant agreement no. 101091933.