

Cloud-Edge-IoT Assets and Patterns

May 2026

Joint publication:

 <p>Alliance for AI, IoT and Edge Continuum Innovation</p>	AIOTI WG Standardisation Task Force High Level Architecture
 <p>CEI-Sphere</p>	CEI-Sphere Horizon Europe project Task force 1 - Architecture
 <p>O-CEI</p>	O-CEI Horizon Europe project
	Resonance Horizon Europe project
 <p>PARMENIDES</p>	Parmenides Horizon Europe project
 <p>eclipse</p>	Eclipse Digital Europe project
 <p>HEDGE-IoT</p>	HEDGE-IoT Horizon Europe project
 <p>HERITWIN</p>	HERITWIN Horizon Europe project
 <p>CTAG</p>	CTAG Automotive Technology Centre of Galicia
 <p>ECLIPSE aeriOS EUROPEAN CLOUD-EDGE-IOT</p>	ECLIPSE open-source project aeriOS
<p>ECLIPSE VOSStack</p>	ECLIPSE open-source project VOSStack

Executive Summary

This report provides an analysis of Cloud-Edge-IoT (CEI) assets and patterns.

It provides the context of EU research projects started in 2018 on projects related to CEI.

It provides a rationale on the need to manage CEI assets, by analysing CEI ecosystems using the hourglass model. It then characterises CEI assets as information technology assets and provides a rationale on the need to create a standard on CEI asset management framework. It lists standards that should be used related to assets, asset assurance, governance, as well as on domain standard on assets such as building information models (BIM).

It describes a number of CEI patterns:

- from the RESONANCE, PARMENIDES, ECLIPSE-DIGITAL, HEDGE-IOT, HERITWIN Horizon Europe projects,
- from CTAG, and
- from two open source initiatives, aeriOS and VOStack.

It concludes with three recommendations:

- Apply for the development of a standard on CEI asset management framework.
- Further improve the description of patterns to capture the essence, i.e. decouple the foundational features from implementation dependent aspects.
- Continue to work in the field of pattern repository to enable the standardization and reusability of architecture patterns.

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1 Context

This document is part of a series of reports published by AIOTI on architecture:

- [Guidance for the Integration of IoT and Edge Computing in Data Spaces](#) (September 2022).
- [Guidance for the Integration of Digital Twins in Data Spaces](#) (August 2024).
- [Towards a Computing Continuum Reference Architecture](#) (May 2025).

They were produced in the context of the cloud-edge-IoT research programme of the European Commission, which has been supported by the cloud, edge, and IoT continuum [initiative](#). This initiative helps support and coordinate [EU research projects](#), including a number of MetaOS projects, aerOS, FluidOS, ICOS, NebulOuS, NEMO, or NEPHELE. More on these projects and others can be found in a [report](#) provided by the OpenContinuum support action.

Upon completion of the MetaOS projects, new projects were started to prepare for deployment of innovation solutions, led by the [CEI-Sphere](#) support action for the development of an open, interoperable, and competitive ecosystem. CEI-Sphere focuses on supporting two major projects, [O-CEI](#) and [Cop-Pilot](#).

This report includes contributions from these projects, but also from, but also engage with other projects such as [HEDGE-IoT](#), [TWIN-EU](#), [ECLIPSE-DIGITAL](#) or [LICORICE](#).

This report includes contributions on cloud-edge-IoT assets from the following projects:

- [O-CEI Horizon Europe project](#).

This report includes contributions on cloud-edge-IoT patterns from the following projects:

- [RESONANCE Horizon Europe project](#).
- [PARMENIDES Horizon Europe project](#).
- [ECLIPSE-DIGITAL Digital Europe project](#).
- [HEDGE-IOT Horizon Europe project](#).
- HERITWIN new Horizon Europe project (project to start in September 2026).
- CTAG project called DRIVING on digital twin and AI for efficiency and sustainability in manufacturing. A video is available [here](#).
- [Aerios Eclipse open-source initiative](#) resulting from the aerOS MetaOS Horizon Europe project.
- [VOStack Eclipse open-source initiative](#) resulting from the Nephele MetaOS Horizon Europe project.

2 Cloud Edge IoT (CEI) Asset Management Framework

2.1 The Need to Manage Assets in the Continuum

Nowadays, there are more than 43 billion devices connected to the Internet, generating, collecting and sharing data¹. From them, 15.14 billion are connected IoT devices, and this figure is expected to double by 2030².

At the same time, artificial intelligence, more especially applied in agentic systems, has demonstrated to be an useful tool for performing operations in highly heterogenous and distributed environments, where different physical resources play a crucial role for performing operations.

The combination of both trends, applying AI techniques to manage IoT assets, has raised the need for an updated digital continuum architecture with enough smart capabilities to bypass resource scarcity issues when dealing with IoT devices.

The work initiated designing a reference architecture for the continuum will be further extended to develop an extended version, with enhanced applied-AI capabilities, specific for novel digital Cloud-Edge-IoT (CEI) asset management. Taking results from new, and ongoing, EU-funded research projects, the approach will be validated with different actors from the continuum value chain from standardization bodies to industry associations, aiming to position Europe ahead of the worldwide competition.

2.2 The Hourglass Model for CEI Assets Ecosystems

Leveraging the results of the CEI-Sphere project on the use of the hourglass model, the O-CEI project has provided the following model shown in Figure 1. It shows the following:

- Stakeholders involve
 - Policy makers who wish to support a market for CEI assets and ensure that they are compliance with regulation,
 - Asset developers who take into account architecture, interoperability and business requirements,
 - Deployment service providers which bundle CEI assets into integrated solutions, and
 - Deployers which deploy CEI assets for their business.
- Capabilities involve
 - Asset lifecycle management based on standards for IT asset description (e.g., ISO/IEC 55000, ISO/IEC 19770 series) and for product description (e.g., TM forum),
 - Deployment document management based on standardized blueprints, and
 - Deployment management based on available asset spaces (also known as market place).

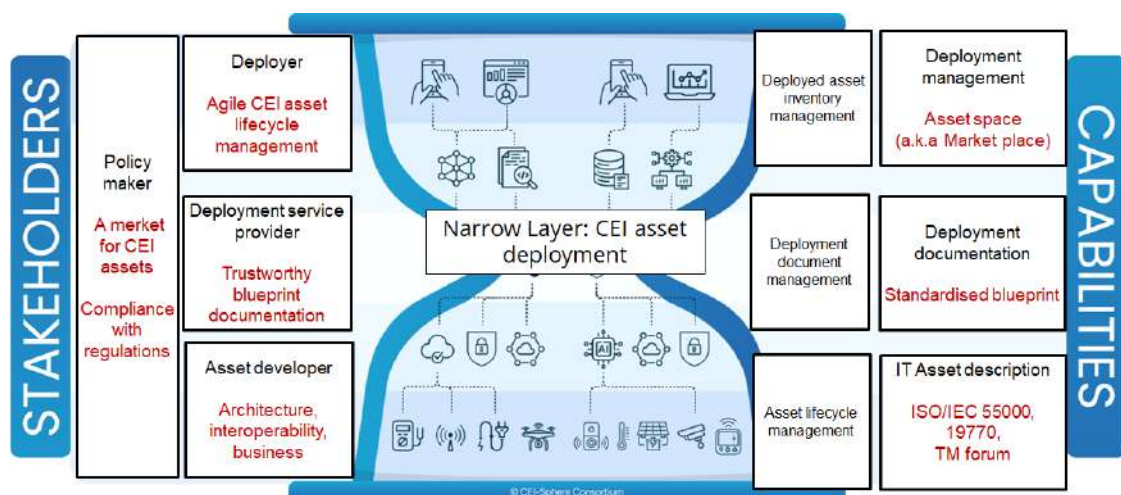


Figure 1 – Hourglass model for CEI asset ecosystems

¹ <https://www.forbes.com/sites/bernardmarr/2022/11/07/the-top-4-internet-of-things-trends-in-2023/>

² <https://explodingtopics.com/blog/number-of-iot-devices>

2.3 Characterisation of CEI Assets

We use the following definitions:

- Asset: Item, thing, or entity that has potential or actual value to an organization (from [ISO 55000](#)).
- Asset management: Coordinated activity of an organization to realize value from assets (from [ISO 55000](#)).
- Bundle: Grouping of products which is the result of a marketing/licensing strategy to sell entitlements to multiple products as one purchased item (from [ISO/IEC 19770-5:2015](#)).
- Software entitlement: Software license use rights as defined through agreements between a software licensor and a software consumer (from [ISO/IEC 19770-3:2016](#)).
- Release: Collection of one or more new or changed configuration items deployed into the live environment as a result of one or more changes (from [ISO/IEC 19770-3:2016](#)).

Types of IT assets according to from ISO/IEC 19770-10 are shown in Figure 2.

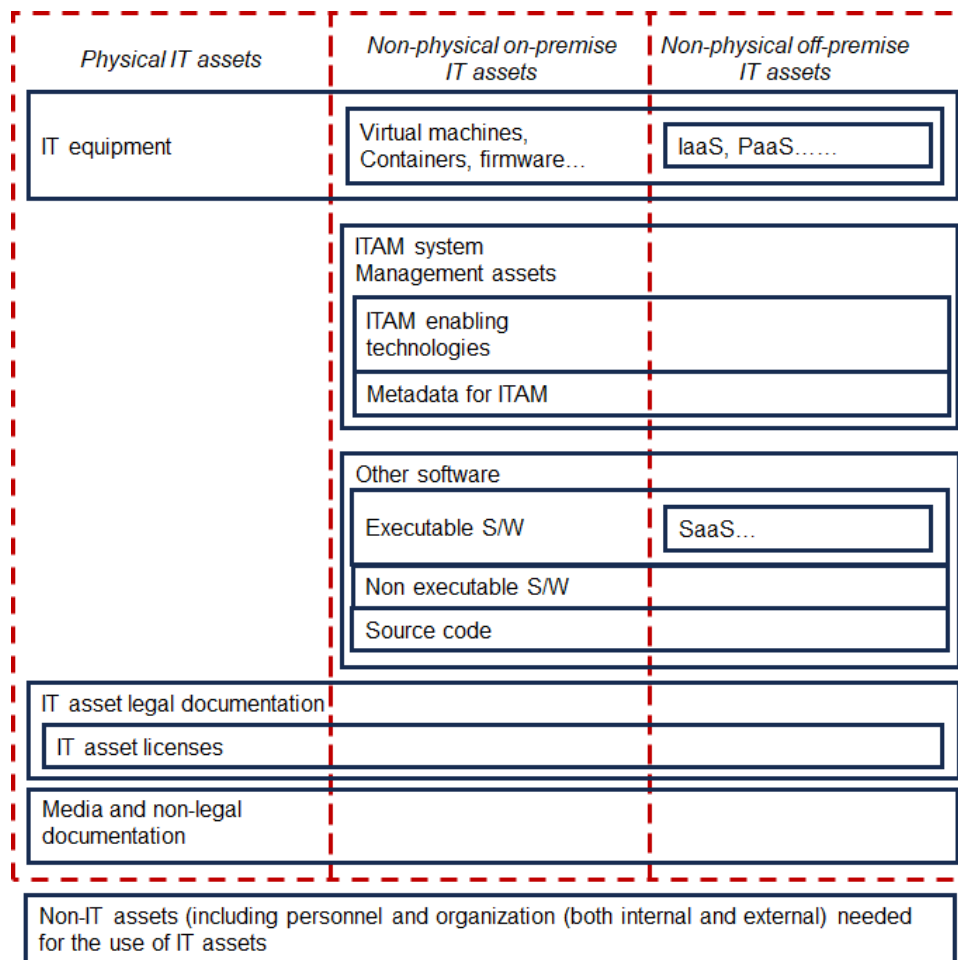


Figure 2 – Types of IT assets (from ISO/IEC 19770-10)

As a first attempt the types of CEI assets according to from ISO/IEC 19770-10 could be those shown in Figure 3.

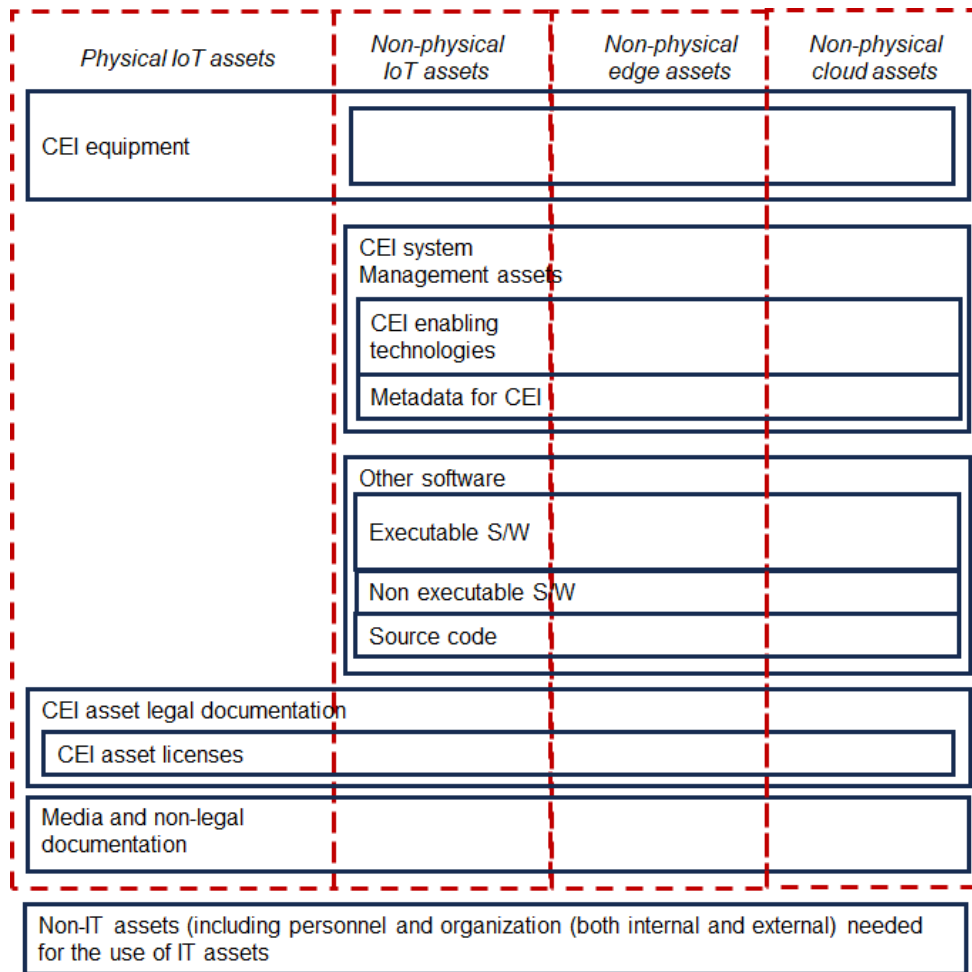


Figure 3 – Types of CEI assets

2.4 The need for a CEI asset management framework standard

2.4.1 The O-CEI project

The [O-CEI](#) project is described as follows:

Through the spread of digitalisation, the Internet of things (IoT) has become increasingly crucial to the everyday functioning of logistics chains, infrastructure, business and more, driving novel solutions and innovations that benefit a wide range of services and sectors. In this context, the EU-funded O-CEI project aims to enhance Europe's competitiveness and strategic autonomy in this sector, recognising the global significance of open cloud-edge IoT. It plans to achieve this by supporting eight pilots in key sectors through the introduction of novel technologies, frameworks and improved data sharing, leveraging shared developments to strengthen each pilot and maximise its potential.

2.4.2 Need for CEI assets management

O-CEI has published a [specification of the open platform](#) that will be used to manage blueprint products in CEI ecosystems. O-CEI uses a number of terms, inspired from the [TM forum](#) as well as [ISO/IEC 19770](#) standards. All these terms can be collectively called *CEI assets*. Here are some examples:

- **Blueprint:** Intentful declarations of an operative target in (one or more) pilots that will have a materialization in terms of O-CEI technological deployment. Blueprints consist of instructions specifically designed to guide a technical rollout of Cloud-Edge-IoT technologies for achieving such target, considering technical elements, strategic conditions, decisions to make, and standards and expert references where they inspire from.
- **Blueprint product:** Technical implementation of a Blueprint framed within the context and operational ecosystem of a specific pilot, incorporating the digital assets required to be materialized (see Digital asset below).
- **Digital asset:** Technical implementation of a Blueprint framed within the context and operational ecosystem of a specific pilot, incorporating the digital assets required to be materialized (see Digital asset below).

- **Blueprint product specification:** Detailed description of a Blueprint product object, including all its digital documentation. This description includes (or points out to) the documentation of all the digital assets that are reused or developed as part of the Blueprint product – including packages and deployment scripts in case of CEI utilities.

2.4.3 The complexity of CEI assets

O-CEI points out the following:

- The need for proper engineering of a CEI asset so that it can be reused, be interoperable, is secure and stable in the long term.
- The need to for capabilities at different layers: federation, application, data and AI, service orchestration, could-edge platform, virtualization, physical resources, IoT/OT device.
- The needs for the following architecture views: functional view, deployment/topology view, process view.

The process view includes the following stages:

- The blueprint product building, of CEI asset building.
- The blueprint instantiation, monitoring and validation, or a CEI asset building validation.
- The blueprint product offering and management, a CEI asset offering and management.
- The storage of a blueprint product in a marketplace, or the exchange of CEI asset in an asset space.

2.4.4 Need for a dataspace for CEI assets, or an asset space

O-CEI is also using the term **digital asset registry**: Private or public component that hosts packaged digital assets (e.g., container images, Helm charts, AI models, etc.), accessible from the Blueprint product builder and operator. This corresponds to an asset space or data space where information exchanged are CEI assets.

Figure 4 shows an example of the type of information that can be associated with the documentation of a CEI asset.

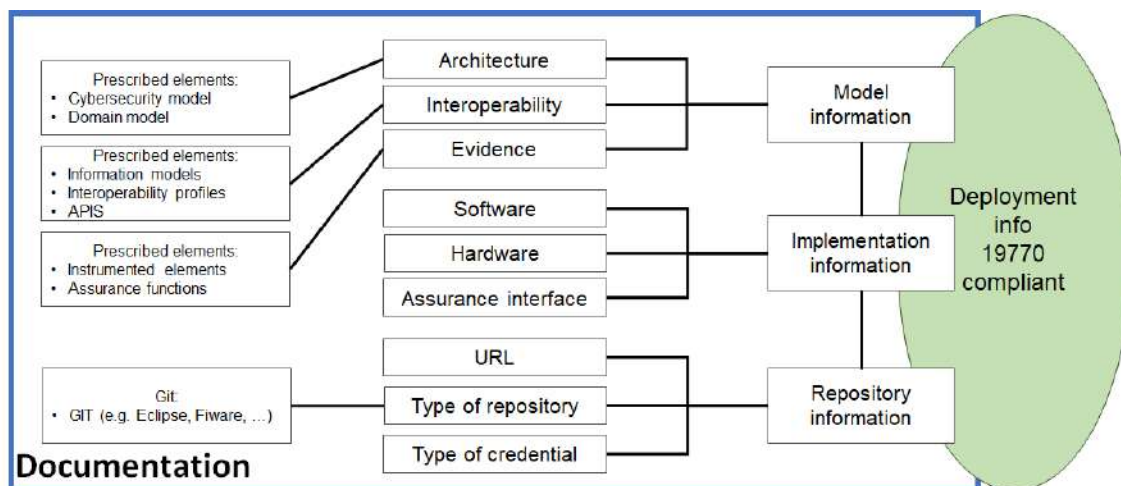


Figure 4 – Documenting a CEI asset

Figure 5 show how participants in an asset space can

- publish a CEI asset in an asset space, and
- use the asset space to access other CEI assets (e.g., A, B, C) and create two other CEI assets (e.g., X bundling A and B, Y bundling B and C).

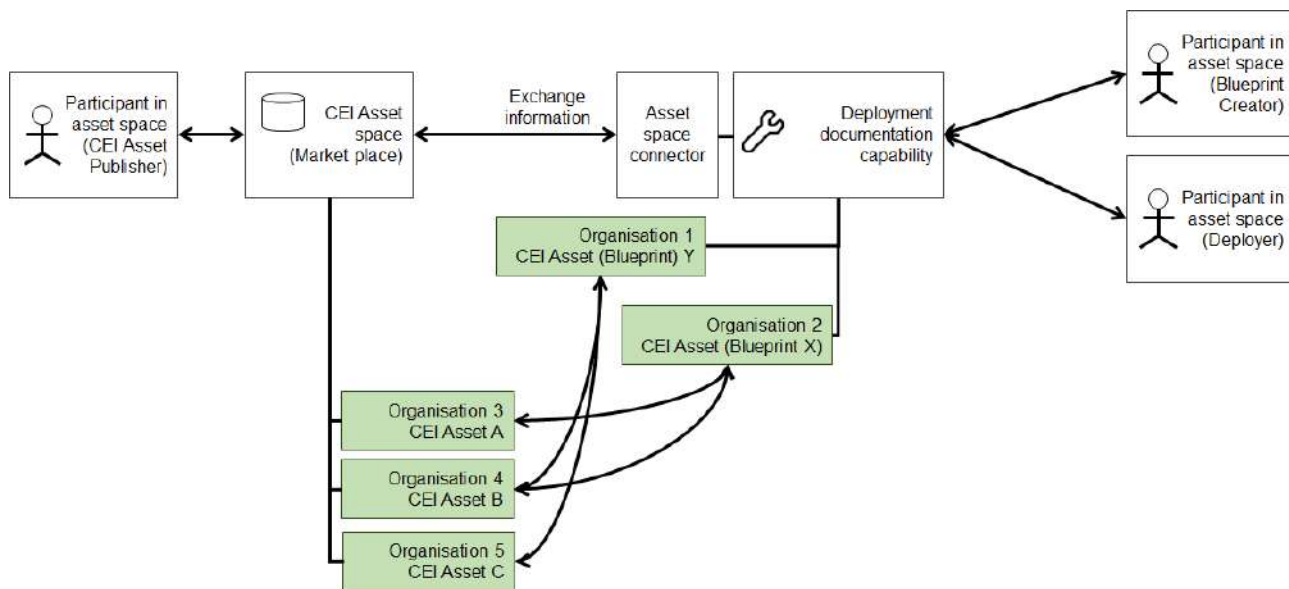


Figure 5 – Building a CEI asset

2.4.1 Need for a CEI asset management framework standard

A CEI asset management framework standard is needed to cope with

- the multiple organisations involved in the provision of a CEI assets,
- the multiple application domains,
- the multiple technologies,
- the multiple lifecycle phases, and
- the multiple description and documentation needs.

2.5 Related standards

The following standards should be used in a future standard on CEI asset management framework

- Standards on assets:
 - [ISO/IEC 19770-1:2017 IT asset management – Part 1: IT asset management systems – Requirements](#),
 - [ISO/IEC 19770-2:2015 Software asset management – Part 2: Software identification tag](#),
 - [ISO/IEC 19770-3:2016 IT asset management – Part 3: Entitlement schema](#),
 - [ISO/IEC 19770-4:2017 IT asset management – Part 4: Resource utilization measurement](#),
 - [ISO/IEC TS 19770-10:2025 IT asset management – Part 10: Guidance for implementing ITAM](#),
 - [ISO/IEC DIS 19770-5 IT asset management – Part 5: Overview and vocabulary](#),
 - [PWI TR JTC1-SC41-36 Considerations for the life cycle of IoT assets](#).
- Standards on asset assurance:
 - [ISO/IEC 19770-11:2021 IT asset management – Part 11: Requirements for bodies providing audit and certification of IT asset management systems](#),
 - [ISO/IEC/IEEE 15026-1:2025 Systems and software assurance. Part 1: Vocabulary and concepts](#),
 - [ISO/IEC/IEEE 15026-2:2022 Systems and software assurance. Part 2: Assurance case](#),
 - [ISO/IEC/IEEE 15026-4:2021 Systems and software assurance. Part 3: Assurance in the life cycle](#).
- Standards on governance
 - [ISO/IEC 38500:2024 Governance of IT for the organization](#),
 - [ISO/IEC FDIS 38501-1 Governance of IT implementation guidance. Part 1: General approach](#),
 - [ISO/IEC TS 38501-2 Governance of IT implementation guidance. Part 2: Assessment scheme and examples](#),
 - [ISO/IEC 38503:2022 Governance of IT – Assessment of the governance of IT](#),
 - [ISO/IEC 38505-1:2017 Governance of data - Application of ISO/IEC 38500 to the governance of data](#),

- [ISO/IEC DTS 38508:2024 - Governance implications of the use of a shared digital service platform among ecosystem organizations.](#)

Furthermore, domain specific standards could also be used. For instance in the BIM (building information model) domain, the following standards could be useful

- [ISO 19650-1:2018 Information management using BIM – Part 1: Concepts and principles,](#)
- [ISO 19650-2:2018 Information management using BIM – Part 2: Delivery phase of assets](#) (planned to evolve toward “Information management process” in the upcoming 2026 revision, covering the full lifecycle of assets),
- [ISO 19650-3:2020 Information management using BIM – Part 3: Operational phase of assets](#) (planned to evolve toward “Implementation of the information management process” in the upcoming 2026 revision),
- [ISO 19650-4:2022 Information management using BIM – Part 4: Information exchange,](#)
- [ISO 19650-5:2020 Information management using BIM – Part 5: Security-minded approach to information management.](#)

3 IoT Patterns

3.1 RESONANCE project

Table 1 describes the application context of the [RESONANCE](#) Horizon Europe project.

Table 1 – RESONANCE project context

Overview	<p>Horizon Europe Strategic Plan 2021 – 2024 aimed, in particular, to make “<i>the energy supply side cleaner, more secure, and competitive by boosting cost performance and reliability of a broad portfolio of renewable energy solutions, in line with societal needs and preferences</i>”.</p> <p>In this framework, the RESONANCE project contributed to the acceleration of the deployment of demand-side flexibility services by developing an innovative software framework that provides means for rapid development and plug-and-play deployment of standard-compliant solutions for demand-side flexibility management (DSFM) across various consumer sectors and energy vectors.</p>
Stakeholders	Energy Suppliers, Grid Operators, Flexibility Service Providers, Industry, Enterprises, Building Managers, District Heating Operator, Charging Station Operators, EV Users, Energy Consumers and Prosumers
Concerns of stakeholders	Interoperability, Data Sovereignty, Trust, Security, Privacy, Compliance, Scalability
Expectations on pattern	<p>Three modular, standard-compliant catalogues of software micro-services: Customer Energy Manager (CEM), Resource Manager (RM) and Aggregation and Market Integration catalogues.</p> <p>Standard-based interoperability across different actors and energy vectors (electricity, district heating).</p> <p>Semantic interoperability at the Resource Manager level to facilitate the onboarding of new assets (EV, PV, batteries, heat pumps ...)</p>

Table 2 describes the pattern.

Table 2 – RESONANCE project pattern

Information	Name	RESONANCE Reference Architecture
	Related patterns	<p>SGAM (standardised pattern)</p> <p>Semantic Interoperability Framework (SIF) pattern from InterConnect</p>
Problem		One of the main challenges to the large-scale deployment of DSFM is the widespread belief that harnessing flexibility from distributed and small-scale assets, such as homes, buildings, and electric vehicles, is not yet cost-effective
Known Context	Specific context	One of the main challenges to the large-scale deployment of DSFM is the widespread belief that harnessing flexibility from distributed and small-scale assets, such as homes, buildings, and electric vehicles, is not yet cost-effective

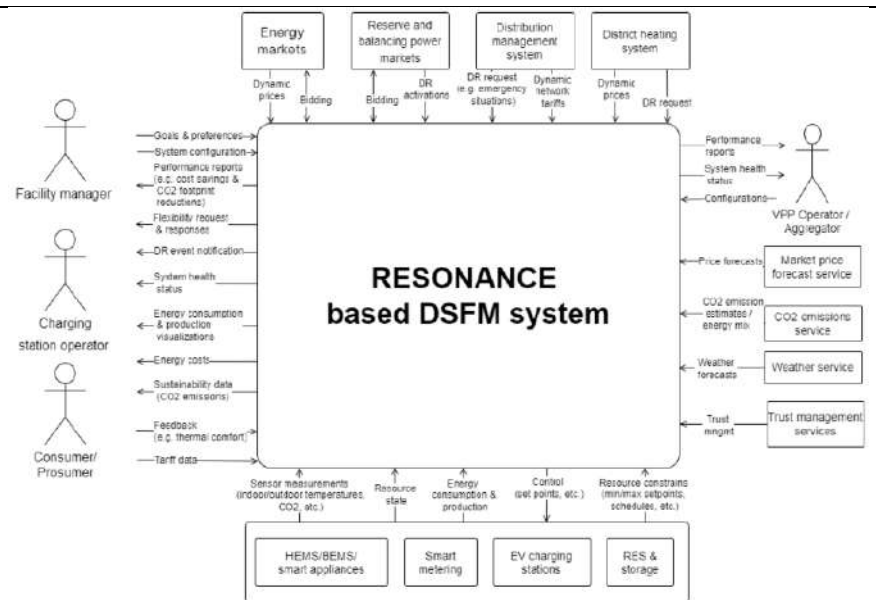


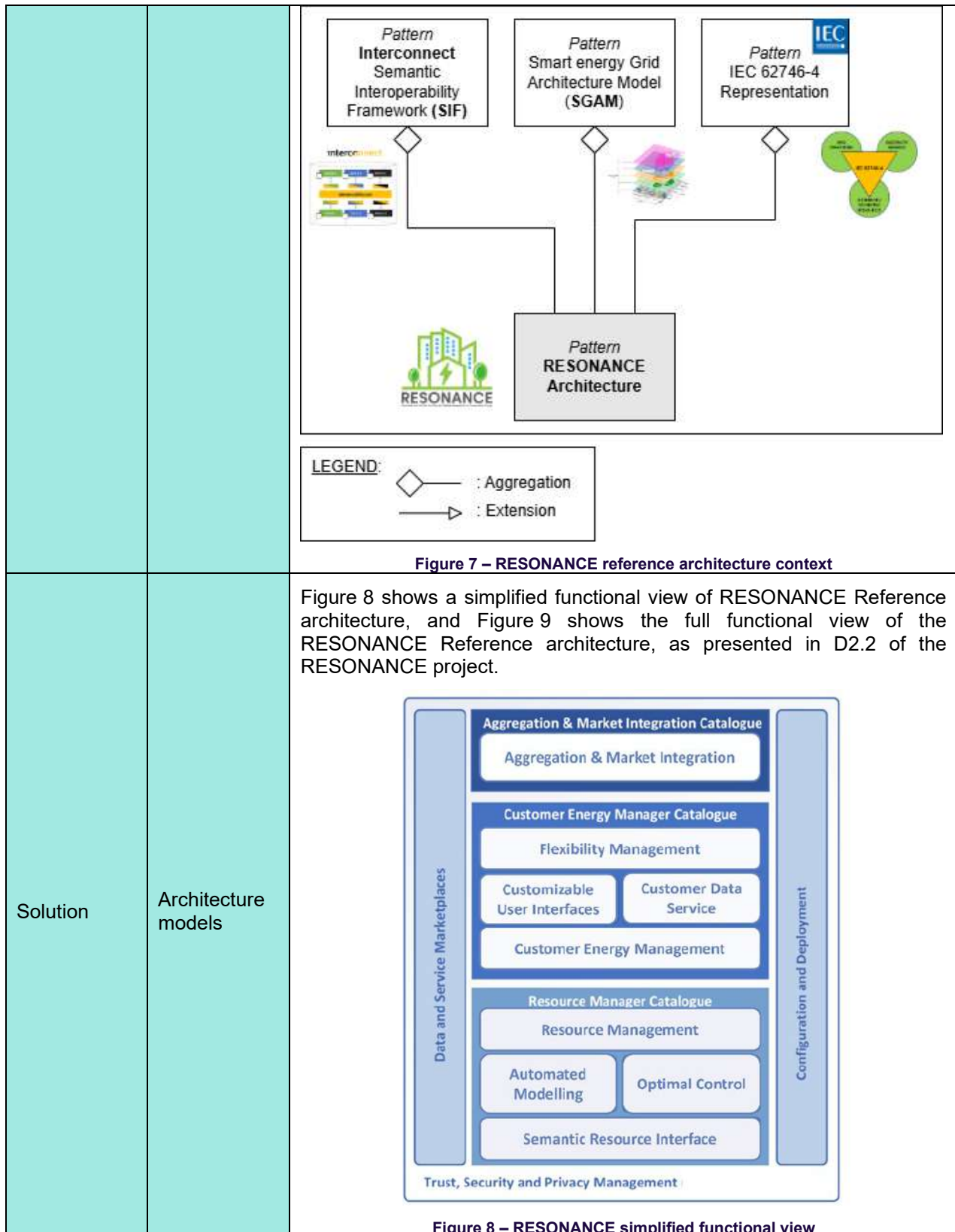
Figure 6 – Context view of a RESONANCE-based DSFM system
Source [D2.2](#) : Final Requirements and Common System Architecture.

Related
context

Energy domain – Demand-side flexibility Management

- The **SGAM pattern** is used universally in the energy domain.
- The **SIF pattern** allows cross-domain semantic interoperability and includes a *Semantic Interoperability Layer* which has been used as an inspiration for the design of the Semantic Resource Interface in the RESONANCE architecture.
- The [IEC SRD 62913-2](#) standards family provides common use cases and requirements which were used in the design of the RESONANCE architecture.
- [EN 50491-12-1](#) and [EN 50491-12-2](#) provide specification for the Customer Energy Manager (CEM) and Resource Manager (RM), which were used in the architecture design of these components and the interface between them (also called “S2 Interface”).
- [IEC TR 62746-2](#) describes the use cases using the interface between a customer energy management system and the power management system, which have been used as input for the design of the CEM and the Aggregation platform of the RESONANCE system.
- [IEC TS 62746-3](#) specifies the overall architecture of the interface between a customer energy management system and the power management system, which has been used to design the architecture of the CEM.
- [IEC 62746-4](#) specifies the Demand Side Resource Interface between a CEM and the power management system, which has been used to design the data model and interface between the CEM and Aggregation platform components in the RESONANCE system architecture.
- The Smart Applications REference ([SAREF](#)) suite of ontologies is a shared model of consensus intended to enable semantic interoperability between solutions from different providers and among various activity sectors in the Internet of Things. SAREF (Core), SAREF4ENER and SAREF4BLDG have been used as the basis for the design of the RESONANCE ontology.

Figure 7 shows the relationships between the RESONANCE Architecture and the related patterns.



		<p>Figure 9 – Functional view of a RESONANCE-based DSFM system</p> <p><i>From D2.2 : Final Requirements and Common System Architecture.</i></p>
	Examples	<p>An implementation of the RESONANCE pattern is described in D2.2 : Final Requirements and Common System Architecture, especially in Section 4 “Architecture Design”.</p> <p>This Section documents the implementation of an example DSFM system, built with the help of the RESONANCE Framework, using ISO/IEC/IEEE 42010:2011 (now available as ISO/IEC/IEEE 42010:2022 after a technical revision).</p>
	Rationale for the pattern	<p>The stakeholders of the energy domain need a standardised and reusable Reference Architecture in order to design, implement and deploy DSFM solutions across EU in an efficient and interoperable manner.</p>
	Guidance	<p>This Pattern is used to design standard-compliant modular and interoperable DSFM systems. Its purpose is to contribute to the acceleration of the deployment of demand-side flexibility services at a large scale to support the electrification of EU and the energy transition.</p>

3.2 PARMENIDES project

Table 3 describes the application context of the [PARMENIDES](#) Horizon Europe project.

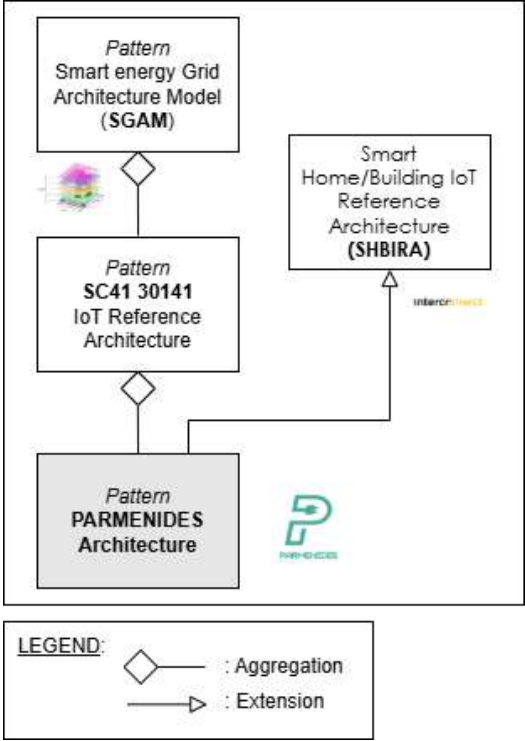
Table 3 – Parmenides project context

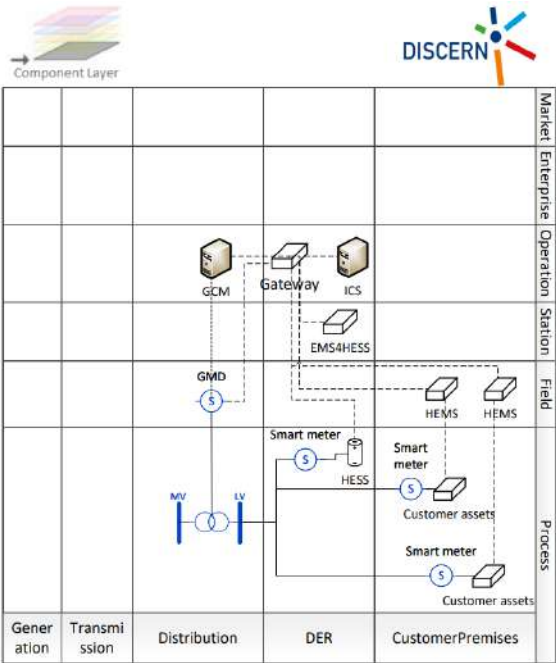
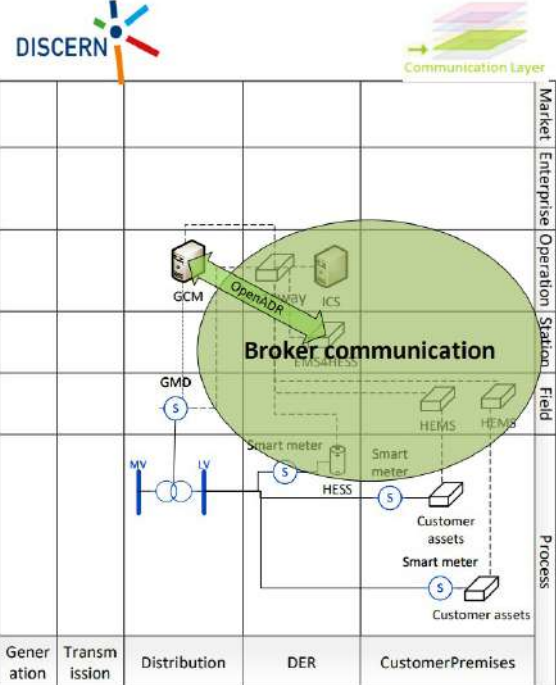
Overview	<p>PARMENIDES: Plug&play eneRgy ManagEmeNt for hybrID Energy Storage</p> <p>PARMENIDES aims to develop a new ontology by extending existing ontologies to provide a knowledge base, with a focus on the electricity and heating domain for buildings, customers, and energy communities. It supports different use cases, focusing on the utilisation of Hybrid Energy Storage Systems (HESS).</p> <p>Besides the representation of storage technologies, information about energy community customers, their behaviours, and components, including their relation are part of the ontology, providing a standardised</p>
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	vocabulary of the domain of energy communities. The name of this ontology is PARMENIDES Energy Community Ontology (PECO).
Stakeholders	<ul style="list-style-type: none"> ▪ Distribution System Operator (DSO) ▪ Energy Supply Company (ESCO) ▪ Energy Community (EC) Participant & EC Manager
Concerns of stakeholders	Interoperability, energy community monitoring/optimisation, compliance, security, scalability, and user involvement level.
Expectations on pattern	Ontology, Hybrid Energy Storage System (HESS), Energy Management System (EMS), Grid Capacity Management (GCM), Information and Configuration System (ICS), smart meter (SM), Applications, and Services.

Table 4 describes the pattern.

Table 4 – Parmenides project pattern

Information	Name	PARMENIDES Architecture pattern
	Related patterns	<ul style="list-style-type: none"> ▪ SGAM (standardised pattern). ▪ SC41 30141 IoT Reference Architecture (standardised pattern). ▪ Smart Home/Building IoT Reference Architecture (SHBIRA) (proposal from the Interconnect project in Deliverable D2.1 Secure Interoperable IoT Smart Home/Building and Smart Energy system Reference Architecture – Chapter 4.3). SHBIRA provides a viewpoint that enables to see the relationship of the digital/IoT platforms. By complying it to the SHBIRA it is possible to add interoperability in a general and unified way instead of specifically per-interface/service.  <p>Figure 10 – PARMENIDES Reference Architecture context</p>
Problem		The ongoing transition of the energy system is accompanied by digitalisation activities, enabling new applications. This results in a fragmentation of existing platforms, protocols, and standards. Therefore, interoperability among various platforms as well as cross-domain interoperability must be ensured.

Known Context	Specific context	<p>PARMENIDES is an European HORIZON project funded by the European Commission in 2022. Project duration January 2023 to December 2025.</p>
	Related context	<p>Energy domain – Energy community</p>
Solution	Architecture models	 <p>Figure 11 – PARMENIDES SGAM architecture – Component layer PARMENIDES SHBIRA</p>
		 <p>Figure 12 – PARMENIDES SGAM architecture – Communication layer</p>

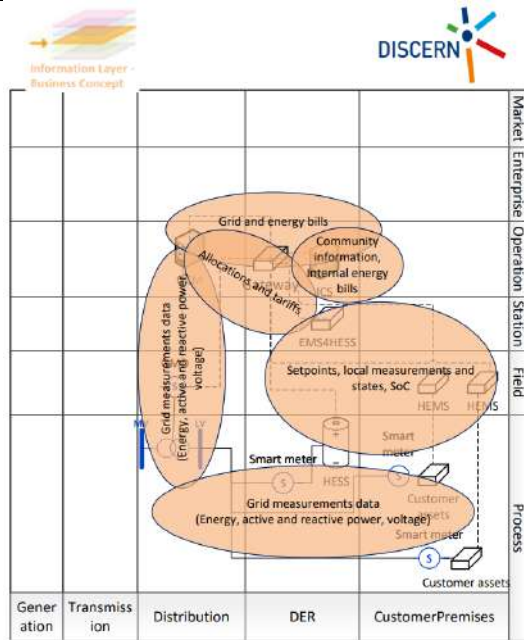


Figure 13 – PARMENIDES SGAM architecture – Information layer

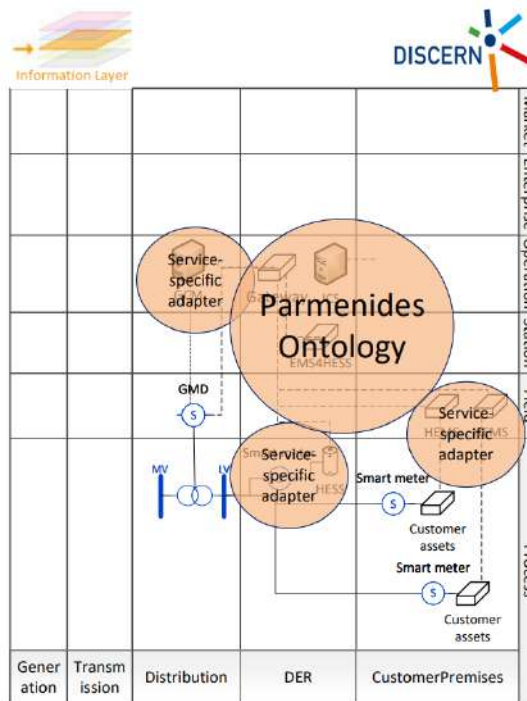


Figure 14 – PARMENIDES SGAM architecture – information layer - Ontology

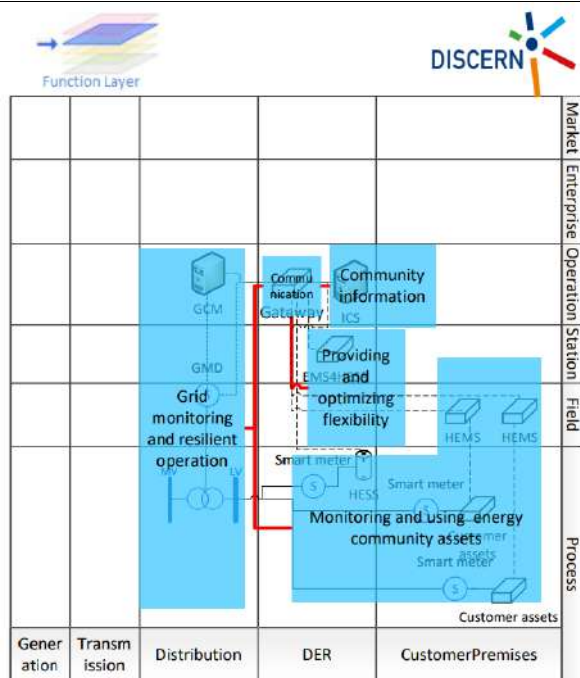


Figure 15 – PARMENIDES SGAM architecture – Function layer

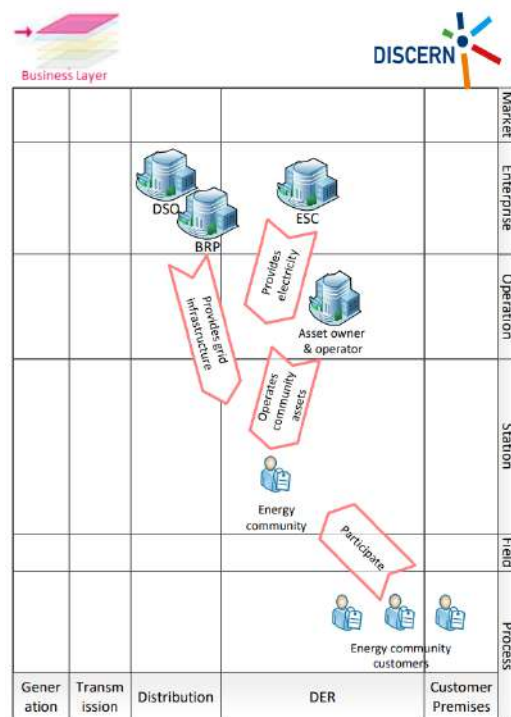
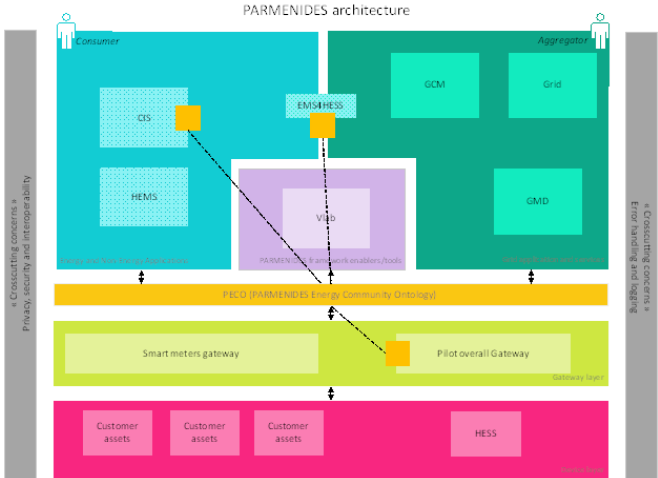
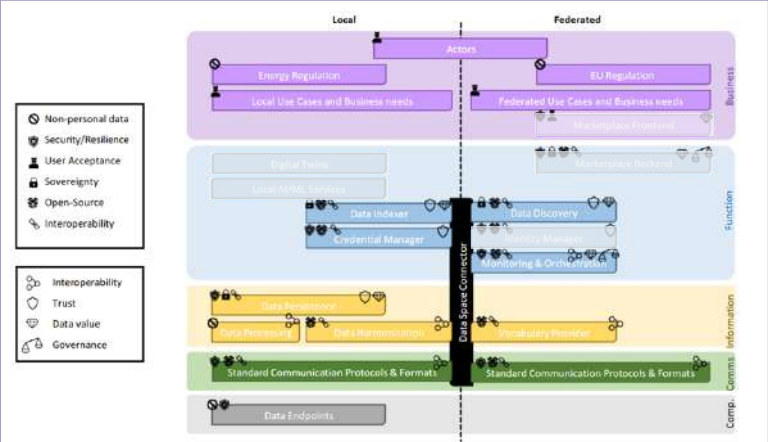


Figure 16 – PARMENIDES SGAM architecture – Business layer

		 <p>Figure 17 – PARMENIDES SHBIRA architecture <i>This includes the ontology implementation by the components (interfaces in yellow)</i></p>
		 <p>Figure 18 – PARMENIDES SHBIRA</p>
	Examples	<p>PARMENIDES pilot implementation could be found in Deliverable D3.1 – PARMENIDES System Architecture – Chapter 6.</p> <p>PARMENIDES business use cases:</p> <ul style="list-style-type: none"> Use case 1: Passive Energy Community Customer Optimization. Use case 2: Active Energy Community Participation. Use case 3: Automated Energy Community Participation with Human Inputs. Use case 4: Fully Automated Energy Community Participation.
	Rationale for the pattern	<p>The PARMENIDES reference architecture pattern has been designed for replicability beyond the project context. It supports speeding up architecture conception while maintaining reusability, scalability, and quality across energy applications.</p> <p>SHBIRA pattern was used in order to describe the DER (Distributed Energy Resources) area, which was the main focus of PARMENIDES project. The SGAM pattern was not precise enough on this specific part.</p>
	Guidance	<p>PARMENIDES pattern:</p> <ul style="list-style-type: none"> is oriented for Energy communities, adds an ontology (i.e., PECO) to the SHBIRA architecture, and uses SHBIRA to describe the DER area of the architecture.

		The developed PECO ontology is used for interoperability within the energy community.
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3.3 ECLIPSE-DIGITAL project

Table 5 describes the application context of the [ECLIPSE-DIGITAL](#) Digital Europe project.

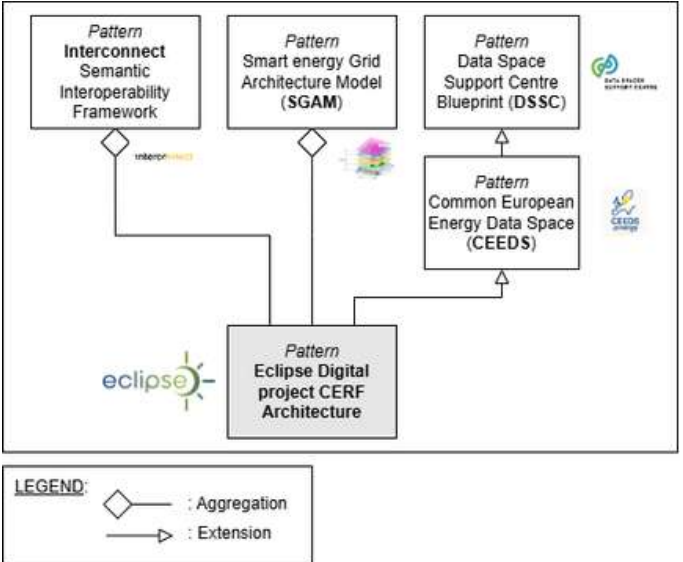
Note: The ECLIPSE-DIGITAL project should not to be confused with Eclipse foundation.

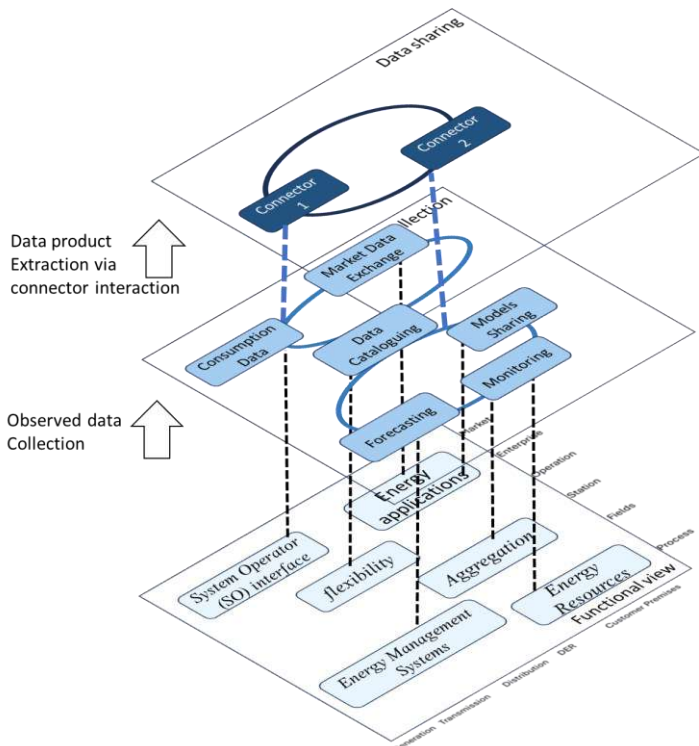
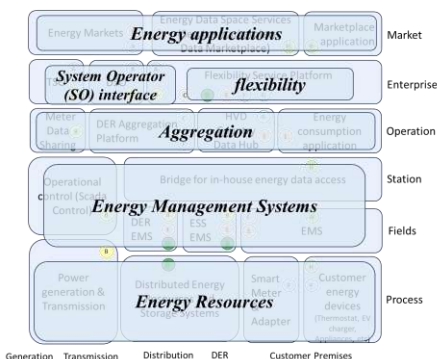
Table 5 – ECLIPSE-DIGITAL project context

Overview	The Common European Reference Framework (CERF) outlines a conceptual four-layer architecture for consumer energy applications, aimed at enabling flexibility on the consumer side. Building on this, the Eclipse-digital project applies ISO/IEC/IEEE 42010 to incorporate stakeholder concerns, define formal viewpoints, and establish layered interoperability profiles.	
Stakeholders	Industry, Enterprises, Data Providers, Data Consumers, Platform Operators, Regulatory, Governance Bodies.	
Concerns of stakeholders	Interoperability, Data Sovereignty, Trust, Security, Compliance, Scalability.	
Expectations on pattern	Data Space Connector, Participant platforms, Applications and Services.	

Table 6 describes the pattern.

Table 6 – ECLIPSE-DIGITAL project pattern

Information	Name	ECLIPSE-DIGITAL Reference architecture
	Related patterns	<ul style="list-style-type: none"> • SGAM (standardised pattern) • SC41 30141 IoT Reference Architecture(standardised pattern) • Initial CERF Architecture • Common European Energy Data Space (CEEDS) architecture  <p>Figure 19 – Patterns used in ECLIPSE-DIGITAL reference architecture</p>
Problem		<p>A broad variety of energy applications has been developed to engage end users through flexibility services and energy-efficiency features.</p> <p>Yet their expansion has revealed fragmentation, limited reuse of architectural knowledge, and inconsistent interoperability approaches.</p>
Known Context	Specific context	ECLIPSE-DIGITAL is an European HORIZON project funded by the European commission.

	Related context	Energy domain – Energy consumption applications SGAM pattern is used universally in the energy domain
Solution	Architecture models	 <p>Figure 20 – ECLIPSE-DIGITAL reference architecture model</p>
	Examples	 <p>Figure 21 – ECLIPSE-DIGITAL reference architecture model Image based on submitted paper for publication</p>
	Rationale for the pattern	To deliver a validated and reusable pattern that speeds up architecture conception while maintaining reusability, scalability, and quality across energy consumption applications.
	Guidance	The pattern can be used to identify components for consumer side flexibility applications, then place connectors and design the architecture through UML like flows connecting them.

3.4 HEDGE-IOT project

Table 7 describes the application context of the [HEDGE-IOT](#) Horizon Europe project.

Table 7 – Hedge-IoT project context

Overview	<p>HEDGE-IOT: Holistic Approach towards Empowerment of the DiGitalization of the Energy Ecosystem through adoption of IoT solutions.</p> <p>HEDGE-IoT is a Horizon Europe Innovation Action that supports the digital transformation of the European energy system through an interoperable IoT-enabled edge-to-cloud framework.</p>
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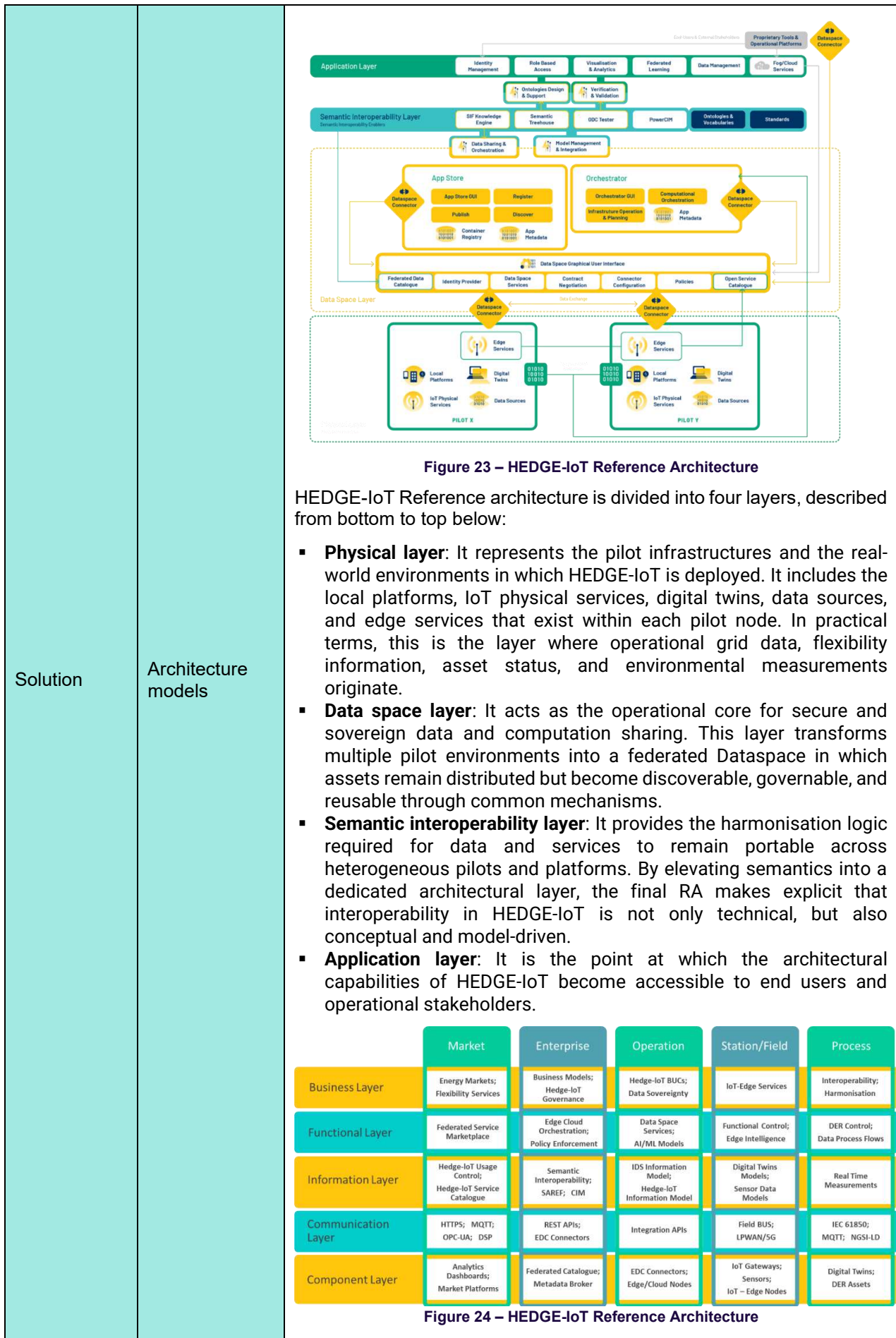
	<p>The project addresses energy-system digitalisation across multiple levels, from behind-the-meter assets to distribution and transmission system operation, with the aim of improving flexibility, resilience, observability and intelligence.</p> <p>Deliverable D2.4, “HEDGE-IoT Reference Architecture — Final Release”, consolidates the final WP2 architectural baseline. It is an architectural consolidation deliverable, not the project’s final implementation or validation report.</p>
Stakeholders	<ul style="list-style-type: none"> ▪ Consumer and Prosumer ▪ Producer ▪ Energy Community (EC) and EC manager ▪ Flexibility Service Provider (including Balancing Service Provider (BSP)) ▪ Energy Service Company (ESCO) ▪ Energy Trader ▪ Meter Operator ▪ Market Operator (including Nominated Electricity Market Operator (NEMO)) ▪ Local Flexibility Market (LFM) ▪ Aggregator ▪ Resource Aggregator ▪ Data Hub Operator ▪ Reserve Allocator (RA) ▪ Reconciliation Responsible ▪ Imbalance Settlement Responsible
Concerns of stakeholders	Interoperability, compliance, security, scalability, governance, trustworthiness, data Sovereignty, and data privacy.
Expectations on pattern	Data space connector, Semantic interoperability enablers, App Store, Computational orchestrator, and security & privacy layer.

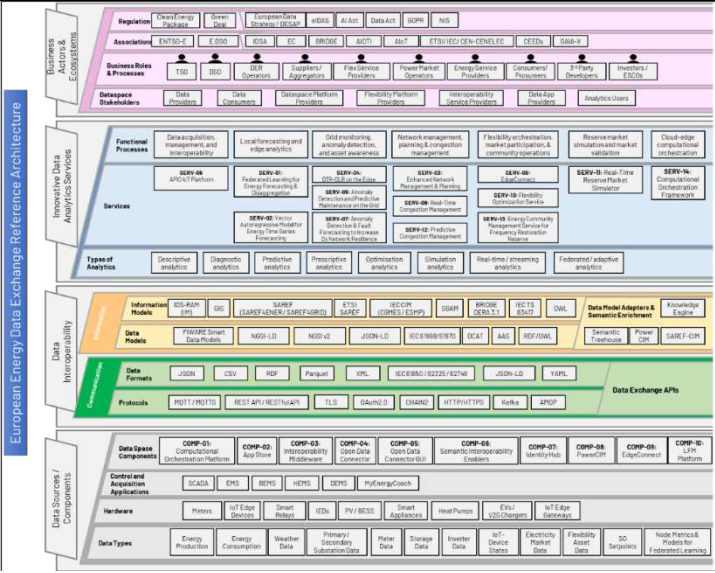
Table 8 describes the pattern.

Table 8 – HEDGE-IOT project pattern

Information	Name	HEDGE-IoT Reference Architecture
	Related patterns	<ul style="list-style-type: none"> ▪ SGAM (standardised pattern) ▪ Common European Energy Data Space (CEEDS) architecture

		<p>Past EU projects' reference architectures used: ATTEST, BRIGHT, Enershare, I-ENERGY, MATRYCS, OneNet, PLATONE, Resonance, SYNERGY</p> <p>Figure 22 – HEDGE-IoT Reference Architecture Pattern context</p> <p>The SGAM pattern is used universally in the energy domain.</p>
Problem		<p>As our world increasingly relies on renewable energy sources, energy systems face unprecedented challenges, and there's a need for new approaches and thorough transformation in common practices.</p> <p>The EU-funded HEDGE-IoT project aims to revolutionise the digitalisation of European energy systems by exploiting the advantages of IoT technologies, deployed at different levels of the power systems, through an interoperable and standardised digital framework.</p> <p>Bridging the edge-cloud continuum through computational orchestration and federated learning traits lies at the centre of the project's activities.</p> <p>The HEDGE-IoT ecosystem will pave the way towards increased grid flexibility, enhanced hosting capacity of renewable energy sources, and a more robust and resilient power system operation.</p>
Known Context	Specific context	HEDGE-IOT is an European HORIZON project funded by the European Commission in 2022. Project duration: January 2024 - June 2027.
	Related context	Energy domain - Grid, grid infrastructure, AI-based energy services, energy community.



		 <p>Figure 25 – BRIDGE DERA Mapping of the HEDGE-IoT Reference ARCHITECTURE</p>
	Examples	<p>HEDGE-IOT Business Use Cases (BUCs), System Use Cases (SUCs), and pilots' implementation could be found on the HEDGE-IOT website, Public deliverable section.</p> <p>BUCs examples:</p> <ul style="list-style-type: none"> ▪ Anomaly detection and fault forecasting in MV distribution network. ▪ Predictive and real-time congestion management (CM) to increase network hosting capacity. ▪ Flexibility management through active prosumers/consumers engagement. ▪ Leveraging data exchange and ai edge algorithms for energy forecasting and prevention of critical grid events. ▪ Flexibility trading platform for mitigating problems of the T&D networks. ▪ Energy flow optimisation with dynamic grid limits. ▪ Flexibility provided by Energy Community to solve a local congestion. ▪ Maximizing asset capacity for increased lifetime of DSO and TSO equipment.
	Rationale for the pattern	<p>The HEDGE-IOT RA pattern has been designed for replicability beyond the project context. It supports speeding up architecture conception while maintaining reusability, scalability, and quality across energy applications.</p> <p>The architecture's alignment with SGAM and BRIDGE DERA, its adoption of IDSA and Gaia-X principles, and its use of established semantic standards (SAREF, CIM) ensure that the framework can be extended and adapted in future energy digitalisation initiatives.</p> <p>The four-layer structure remains flexible enough to accommodate emerging technologies (new AI/ML models, evolving communication protocols, advanced edge hardware) while maintaining core architectural principles.</p>
	Guidance	<p>The pattern can be used to identify components for grid infrastructure, energy community, and flexibility applications. Then, connectors could be placed and the architecture designed.</p>

3.5 HERITWIN cultural heritage digital twin

Table 9 describes the application context of the HERITWIN Horizon Europe project. The project will start in September 2026.

Table 9 – HERITWIN project context

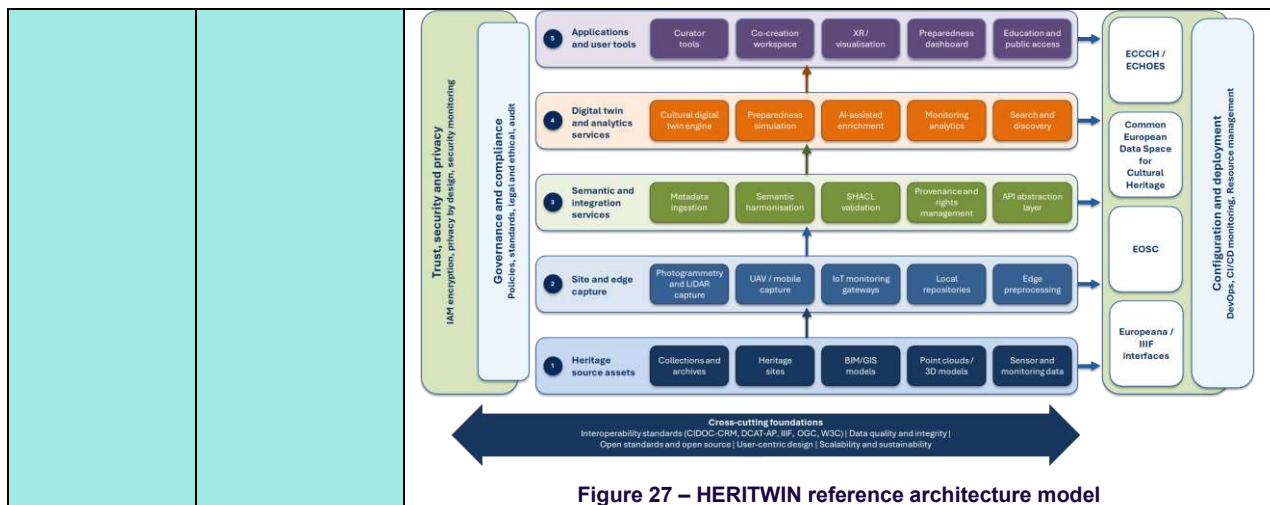
Overview	<p>HERITWIN validates cultural heritage digital twins as Cloud-Edge-IoT assets within the emerging European Collaborative Cloud for Cultural Heritage (ECCCH).</p> <p>The project combines semantic interoperability, digital twin modelling, XR, AI-assisted enrichment, preparedness simulation and controlled data sharing across five pilots in Sweden, Norway, Spain, the United Kingdom and Greece.</p> <p>The relevant CEI assets include physical heritage sources, digital representations, semantic models, software services, metadata pipelines, sensor streams, validation evidence and deployment blueprints.</p>
Stakeholders	Cultural heritage institutions, museums, archives, archaeological authorities, regional and municipal heritage owners, researchers, digital heritage SMEs, platform operators, data-space actors, standardisation bodies, civil-protection actors, educators, local communities and visitors.
Concerns of stakeholders	Semantic interoperability, provenance, trust, data sovereignty, controlled access to sensitive heritage information, FAIR data management, long-term preservation, AI transparency, accessibility, environmental sustainability, cybersecurity, regulatory compliance and operational validation.
Expectations on pattern	A reusable cultural heritage digital twin pattern for data capture, semantic enrichment, site/edge monitoring, cloud-based digital twin services, ECCCH/data-space integration, validation reporting, controlled disclosure and standards-aligned replication.

Table 10 describes the pattern.

Table 10 – HERITWIN project pattern

Information	Name	HERITWIN ECCCH-aligned Cultural Heritage Digital Twin Pattern
	Related patterns	<ul style="list-style-type: none"> ▪ ECCCH/ECHOES preliminary cloud architecture; ▪ ISO/IEC/IEEE 42010; ▪ ISO/IEC 30141; ▪ CEI asset-management framework; ▪ CIDOC-CRM/ISO 21127; ▪ EDM; ▪ DCAT-AP; ▪ IIIF; ▪ FAIR; ▪ SHACL; ▪ W3C Web of Things where IoT device abstraction is required.
Problem		<p>Cultural heritage digitisation often produces isolated 3D models, metadata records, XR applications or monitoring systems that cannot be reused across institutions, data spaces or operational contexts.</p> <p>This limits validation, trust, provenance, preparedness and long-term asset management.</p>
Known Context	Specific context	HERITWIN is a Horizon Europe cultural heritage digital twin project validating ECCCH-relevant workflows through five operational use cases: archival reconstruction, canal preparedness, pilgrimage heritage, micro-climate monitoring and archaeological XR documentation.
	Related context	<ul style="list-style-type: none"> ▪ Cultural heritage; ▪ Cloud-Edge-IoT continuum; ▪ European data spaces; ▪ ECCCH;

		<ul style="list-style-type: none"> ▪ EOSC; ▪ digital twin-based conservation; ▪ XR interpretation; ▪ AI-assisted metadata enrichment; ▪ IoT-supported environmental monitoring.
Solution	Architecture models	<p>The pattern organises heritage assets into a layered workflow:</p> <ul style="list-style-type: none"> ▪ source assets and physical sites; ▪ site/edge capture and monitoring; ▪ semantic harmonisation; ▪ cultural digital twin services; ▪ ECCCH/data-space interfaces; ▪ governance, access control and validation evidence. <p>Figure 12 provides the simplified view.</p> <p>Figure 26 – Pattern relationships in the HERITWIN architecture</p>
	Examples	<p>UC2 Telemark Canal applies the pattern to preparedness modelling by combining spatial documentation, BIM/GIS, selected monitoring data, semantic metadata and digital twin-based scenario analysis.</p> <p>UC1 and UC5 apply it to reconstruction and XR interpretation; UC4 applies it to micro-climate monitoring and conservation</p>
	Rationale for the pattern	<p>The pattern turns cultural heritage digitisation outputs into managed CEI assets that can be described, governed, validated, versioned, accessed and replicated.</p> <p>It supports future ECCCH alignment without making implementation dependent on immature platform specifications.</p>
	Guidance	<ul style="list-style-type: none"> ▪ Identify physical, digital, semantic and software assets. ▪ Define ownership and access constraints. ▪ Map metadata to CIDOC-CRM, EDM and DCAT-AP. ▪ Package reusable outputs according to FAIR. ▪ Validate semantic quality through SHACL. ▪ Document AI-assisted enrichment. ▪ Expose controlled APIs. ▪ Maintain a maturity register for ECCCH/ECHOES dependencies.



3.6 CTAG – Driving project

Table 11 describes the application context of the Driving project from CTAG.

Table 11 – CTAG - Driving project context

Overview	Driving Architecture
Stakeholders	 <p>Nightingale HQ, Oven SL, CTAG- Automotive Technology centre of Galicia</p>
Concerns of stakeholders	<p>Stakeholders need to understand how energy consumption, waste generation and process performance vary depending on machine state, production activity, process parameters, quality data and environmental conditions.</p> <p>Their main concerns include identifying inefficient behaviours, abnormal consumption patterns, idle consumption, production bottlenecks and energy peaks during specific manufacturing phases.</p> <p>From a business and sustainability perspective, they aim to reduce operational costs, material waste and carbon emissions, while improving productivity, competitiveness, compliance and decision-making. From a technical perspective, they are concerned with integrating heterogeneous data sources such as PLCs, energy meters, controllers, sensors, digital tools and external systems, ensuring reliable data acquisition, interoperability, scalability, data quality and compatibility with existing industrial infrastructures.</p>
Expectations on pattern	<p>The pattern is expected to provide a structured, scalable and modular architecture to correlate energy consumption data with machine states, production context, process metadata, quality data and environmental variables.</p> <p>It should enable near real-time monitoring, detailed energy and sustainability analysis, digital twin visualisation, AI-based correlation discovery, prediction and optimisation.</p> <p>As a result, the pattern should generate correlated datasets, dashboards, energy consumption profiles by machine state or production phase, anomaly detection inputs, process-efficiency indicators, sustainability KPIs and evidence to support optimisation actions.</p>

Table 12 describes the pattern.

Table 12 – CTAG - Driving project pattern

Information	Name	Driving Architecture
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	Related patterns	N/A for the moment
Problem		<p>Manufacturing companies often analyse energy consumption, process performance and sustainability indicators separately, without correlating them with the real operational context of the factory. This limits the ability to understand why energy is consumed, where waste is generated, which machine states are inefficient, or how process conditions affect productivity and emissions.</p> <p>The Driving Architecture addresses this problem by unifying energy consumption recordings with the operational state of the machine, production activity, process metadata and environmental information, enabling a more precise analysis of energy behaviour and its relationship with the actual manufacturing process.</p> <p>Manufacturing companies often analyse energy consumption, process performance and sustainability indicators separately, without correlating them with the real operational context of the factory. This limits the ability to understand why energy is consumed, where waste is generated, which machine states are inefficient, or how process conditions affect productivity and emissions.</p> <p>The Driving Architecture addresses this problem by unifying energy consumption recordings with the operational state of the machine, production activity, process metadata and environmental information, enabling a more precise analysis of energy behaviour and its relationship with the actual manufacturing process.</p>
Known Context	Specific context	<p>In many industrial environments, energy consumption is monitored in an isolated way, disconnected from production events, machine states, product information, quality indicators or environmental conditions.</p> <p>This provides shallow information and makes it difficult to identify the root causes of inefficiencies. DRIVING proposes a digital and sustainability-oriented approach based on digital twins, artificial intelligence, advanced data analysis and real-time visualisation.</p> <p>The objective is to provide manufacturers with tools to improve quality, flexibility, efficiency and productivity, while reducing waste and carbon emissions.</p>
	Related context	<ul style="list-style-type: none"> ▪ Energy domain – energy consumption analysis. ▪ Sustainable manufacturing. Industrial digitalisation. ▪ Industry 4.0 and 5.0. ▪ Digital twin-based process monitoring. ▪ AI-supported production optimisation. ▪ Carbon-aware production planning. ▪ Real-time dashboards and sustainability KPIs.

Solution	Architecture models	<p>Figure 28 – DRIVING project architecture models</p>
Examples		<p>Driving has been deployed successfully in our Process Simulation Laboratory monitoring a simulated industrial process and giving key insights on energy consumption across the process</p>
Rationale for the pattern		<p>The rationale of the pattern is to move from isolated energy measurements to contextualised sustainability intelligence. By correlating raw energy consumption with machine status, production events, quality information, process variables and environmental conditions, manufacturers can understand not only how much energy is consumed, but also why, when and under which operational conditions it is consumed.</p> <p>This supports better decisions, more efficient production planning, reduction of waste and emissions, and improved competitiveness.</p>
Guidance		<p>To use or replicate the pattern, the following steps should be followed:</p> <ul style="list-style-type: none"> install the required components in the main controller or industrial edge node; configure PLCs, energy meters, sensors and other edge devices to send data to the ETL/data pipeline; define the relevant machine states, such as running, idle, warming up, stopped, maintenance or fault; identify the contextual metadata required for analysis, such as product reference, job ID, batch, process phase, production order, quality data or environmental temperature; develop adapters or APIs for incompatible or legacy devices; ensure the required network connectivity between shopfloor equipment, edge components and the data platform; synchronise timestamps across all data sources; validate data quality, completeness and frequency; configure dashboards, KPIs and the digital twin visualisation layer; and

		<ul style="list-style-type: none"> ▪ apply AI or analytics tools to detect correlations, rules, anomalies and optimisation opportunities.
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3.7 aeriOS

Table 13 describes the application context of the Eclipse [aeriOS](#) open-source project resulting from the aerOS Horizon Europe project.

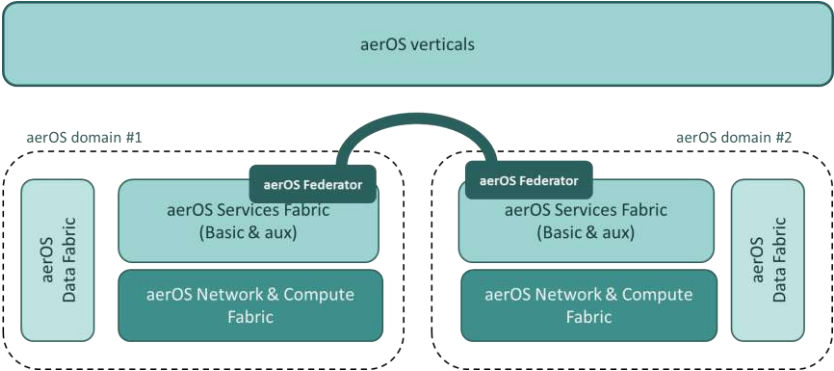
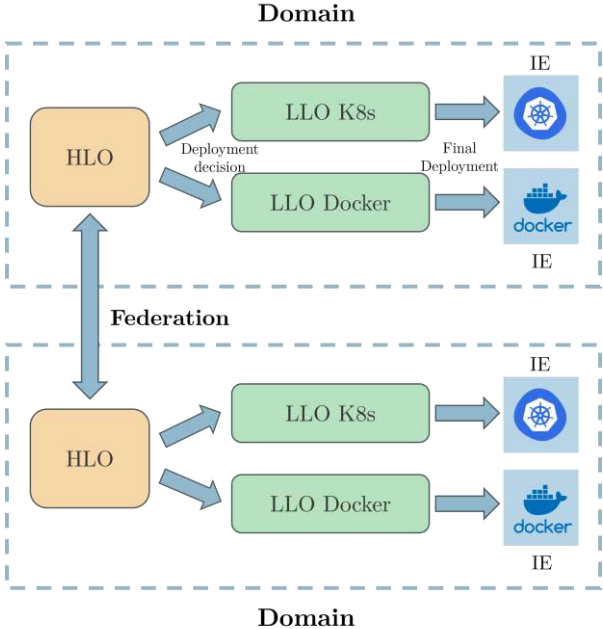
Table 13 – aeriOS open-source context

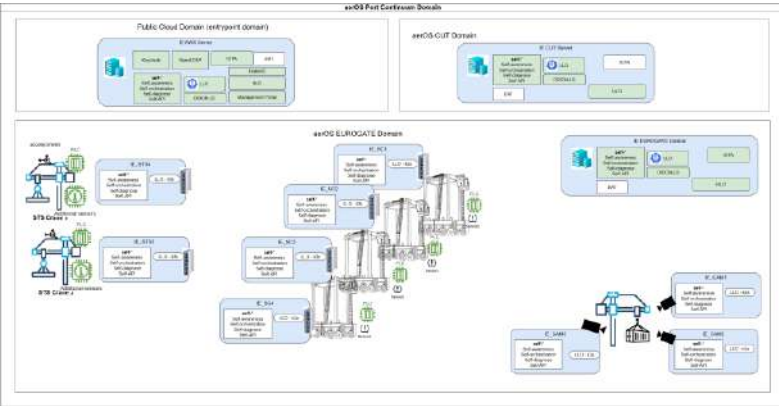
Overview	<p>Eclipse aeriOS is an open-source Meta-Operating System designed to govern the Cloud–Edge–IoT continuum, enabling federated orchestration and unified management of distributed computing resources across heterogeneous infrastructures (IoT, edge, cloud).</p> <p>It stems from the Horizon Europe aerOS project and is incubated under the Eclipse Foundation.</p>
Stakeholders	<ul style="list-style-type: none"> ▪ IoT devices owners. ▪ Edge computing integrators. ▪ Cloud providers. ▪ IT System Administrators.
Concerns of stakeholders	<ul style="list-style-type: none"> ▪ heterogeneity of infrastructures; ▪ interoperability across domains and vendors; ▪ workload orchestration across cloud-edge-IoT; ▪ decentralized governance; ▪ observability and monitoring; ▪ trustworthiness; ▪ scalability; ▪ avoidance of vendor lock-in; <p>performance-aware placement.</p>
Expectations on pattern	<p>The view should be capable of the following:</p> <ul style="list-style-type: none"> ▪ Receive the descriptive information of a workload to be deployed (e.g., AI model, one-shot tasks...). ▪ Capture (in a homogenised way) the current status of all computing elements belonging to a continuum. ▪ Select the best candidate for running the specified workload. ▪ Properly commissioning (order) the execution. ▪ Effectively run the service in the selected environment, respecting the constraints and ancillary values provided by the user. ▪ Allow the stop, deletion and re-orchestration of the workload.

Table 14 describes the pattern.

Table 14 – aeriOS meta-OS pattern

Information	Name	Eclipse aeriOS Meta-OS Pattern
	Related patterns	<ul style="list-style-type: none"> ▪ VOSStack (Nephele)
Problem		How to transparently orchestrate and manage containerized workloads across heterogeneous, distributed and multi-domain Cloud–Edge–IoT infrastructures while avoiding centralization and vendor lock-in.
Known Context	Specific context	ECLIPSE aeriOS has stemmed from an European HORIZON project funded by the European commission (HE aerOS).
	Related context	<p>It responds to the following contextual challenges existing in the Cloud–Edge–IoT field:</p> <ul style="list-style-type: none"> ▪ Provides a uniform control and management layer across a heterogeneous, distributed continuum

		<ul style="list-style-type: none"> ▪ Extends the basic functionalities provided by a conventional OS to the CEI continuum <ul style="list-style-type: none"> ○ Continuum-wide monitoring and observability ○ Abstraction of compute, network and data resources ○ Unified orchestration and lifecycle management of applications and services across domains.
Solution	Architecture models	<p>It follows an architecture model known as “edge-native federation” based on the federation of domains. Domains may belong to different organizations and expose heterogeneous runtime capabilities and are composed of Infrastructure Elements, which are the actual computing units.</p>  <p>Figure 29 – Aerios federated architecture</p> <p>Two-layer federated orchestration architecture. aeriOS introduces Infrastructure Elements (IEs) grouped into domains, federated through decentralized coordination.</p> <p>High-Level Orchestrators (HLOs) make workload placement decisions using global awareness, while Low-Level Orchestrators (LLOs) execute deployments locally.</p> <p>Unified APIs, NGSI-LD context management, observability tooling and secure networking provide interoperability and seamless control</p>  <p>Figure 30 – aeriOS two-layer federated orchestration</p>

		<p>The Meta-OS has been used in this example to deploy computer Vision in detection of defects in containers in the port of Limassol (pilot of aerOS project).</p> <div data-bbox="566 313 1284 645">  </div> <p>Figure 31 – aerIOS application example (detection of defects in containers)</p> <p>Thus, an example could be: to perform inference of computer vision AI-based algorithms on distributed edge environments.</p> <p>IPTV cameras are installed at the terminal dock, next to STS cranes. They record the loading and unloading of containers to or from vessels.</p> <p>This use case allows a maritime terminal to automatically identify containers with damages, and to check for the existence of container seals without the need of human intervention, avoiding subjective mistakes and reducing safety risks, by achieving a secure, and trustable environment for terminal staff.</p> <p>In this example, the aerIOS Meta-OS pattern would solve the issues of</p> <ul style="list-style-type: none"> ▪ uniting the capacities of an edge element (e.g., Nvidia Jetson) to cooperate with an IoT device that captures data (e.g., images from IPTV camera) and to run AI training and inference processes together with local (e.g., servers) and cloud (e.g., AWS) computation resources, ▪ allowing several stakeholders to participate in the process, providing infrastructure elements, and ▪ control the lifecycle of the inference application (stop, delete, re-orchestrate). <p>In this case, the Infrastructure Elements and Domains topology must be described. An example would be as follows:</p> <div data-bbox="566 1444 1348 1848">  </div> <p>Figure 32 – aerIOS example infrastructure description</p> <p>Also, certain components (implying monitoring, security, API exposure) must be installed/compliant with.</p>
	<p>Rationale for the pattern</p>	<ul style="list-style-type: none"> ▪ distributed service execution; industrial IoT orchestration; smart city services; ▪ cross-domain edge deployments;

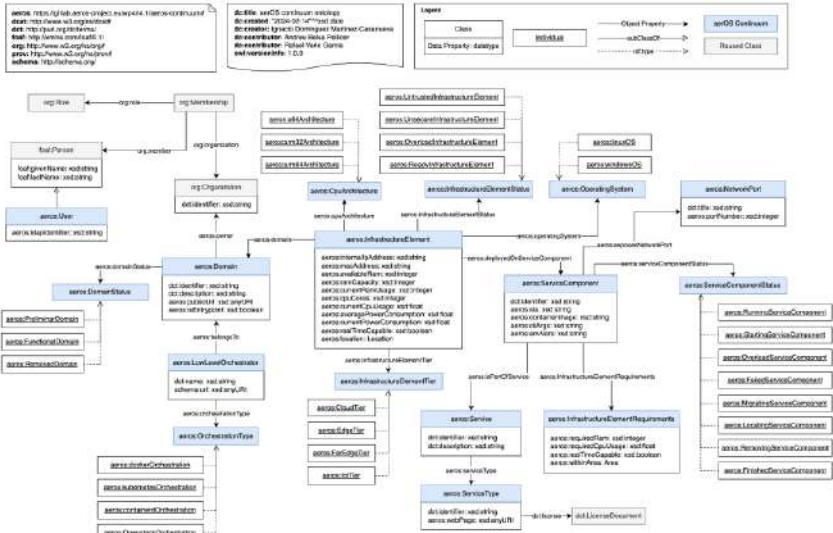
		<ul style="list-style-type: none"> ▪ benchmark-aware workload placement; ▪ dynamic service deployment across cloud-edge environments. <p>For the concrete example mentioned, the rationale could be summarised as follows:</p> <ul style="list-style-type: none"> ▪ Encompasses all the stages needed to train a model and perform the inspection in a heterogeneous distributed environment. ▪ Provides a flexible framework to select where a service should run. ▪ Provides a logical (and technological) way of expressing computing elements organised in tiers and domains.
	Guidance	<ul style="list-style-type: none"> ▪ adopt a domain-based federation model; ▪ expose resources through standard APIs and semantic models (e.g., NGSI-LD); ▪ separate high-level placement decisions from local execution; integrate observability and benchmarking; ▪ support heterogeneous runtimes (e.g., Kubernetes, Docker); ▪ avoid centralized single points of failure; ▪ design for extensibility and interoperability with future runtimes and standards. <p>For using/replicating the pattern, the following should be considered:</p> <ul style="list-style-type: none"> ▪ Installation of components in the main cloud domain. ▪ Installation of components in the edge and the rest of domains. ▪ Installation of orchestration capabilities. ▪ Installation of a management portal. ▪ Development of an AI model for damage inspection (or any other maintenance/surveillance case). ▪ Setup the necessary network connectivity setup. <p>Follow the specification of aerOS Continuum Ontology:</p> 

Figure 33 – aerOS continuum ontology

3.8 VOSStack

Table 15 describes the application context of the Eclipse [VOSStack](#) open-source project resulting from the NEPHELE Horizon Europe project.

Table 15 – VOSStack open-source context

Overview	An IoT and Edge computing software stack -called as Eclipse VOSStack- is designed to leverage the virtualization of IoT devices at the edge infrastructure.
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	<p>This stack supports openness and interoperability in a device-independent manner. Through this software stack, management of diverse IoT devices and platforms can be unified, eliminating the need for middleware platforms.</p> <p>Edge computing functionalities can be dynamically provided to efficiently support IoT applications.</p> <p>Eclipse VOSTack is considered an enabler for the development of Digital Twins in various industrial sectors.</p> <p>Eclipse VOSTack is aligned with the W3C Web of Things Standard and was initially developed within the NEPHELE Horizon Europe project.</p> <p>Definitions:</p> <p>A Virtual Object (VO) is considered as a virtual counterpart of a physical device on the Internet of Things domain. It provides a set of abstractions for managing any type of IoT device through a virtualized instance while augmenting the supported functionalities through the development of the Eclipse VOSTack.</p> <p>A Composite Virtual Object (cVO) is a software entity that can manage the information coming from one or multiple VOs and provide advanced functionalities.</p> <ul style="list-style-type: none"> ▪ The cVO interacts with the VOs, processes the collected information, and can contextually produce advanced knowledge, by enabling the communication and collaboration of several VOs, toward the production and exposure of a combined set of data outputs. ▪ Under the scope of this mode, the cVO can operate also as a Digital Twin (DT). In this case, the enhanced capabilities of the VO through the cVO refer to the support of simulation, integration, testing, monitoring, and maintenance activities for an IoT device. <p>The Digital Twin refers to a composition of VOs and cVOs and aims to monitor, simulate, predict, diagnose, and control the state and behavior of one or more physical devices.</p> <p>The Digital Twin Network is a virtual representation of a communication network topology that connects VOs, and cVOs and enables their interaction. It also supports communication with the IoT application components.</p> <p>The Application Graph is a graph, where the nodes of the graph refer to application components (or microservices) and the links of the graph represent the interactions (or dependencies) among the application components. VOs and cVOs can be part of an Application Graph.</p>
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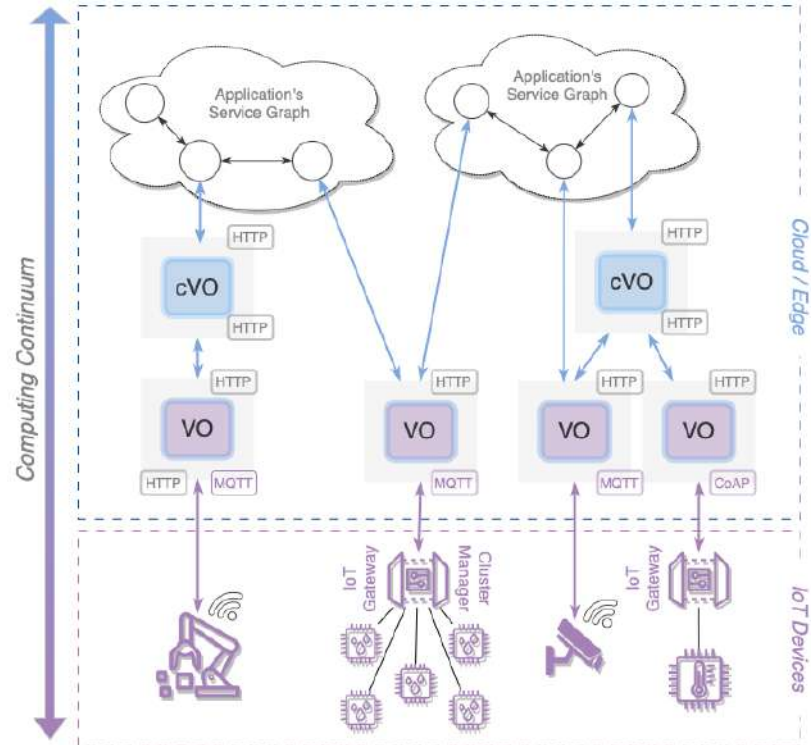


Figure 34 – Overview of VOs, cVOs and Application Graphs

Stakeholders

Cloud-Edge Provider (CEP): corresponds to the infrastructure provider in terms of computation and storage resources. The major responsibility of the CEP is the offering of resources and the effective management and orchestration of the distributed applications deployed across the IoT-to-Edge-to-Cloud continuum. Furthermore, the hardware infrastructure of the IoT devices and end-servers are considered as part of the available end-to-end infrastructure. CEP integrates decisions within the orchestration actions, exploiting advances provided by several Artificial Intelligence (AI) technologies in features detection and inference and leading to the optimal management of the interplay among edge and cloud resources.

Internet of Things (IoT) Provider: provides access to IoT infrastructure that is already deployed and operational (e.g., IoT infrastructure that exists in smart cities). Such infrastructure can be used by edge/cloud orchestration platforms through the provision of virtual counterparts of the IoT devices and their interlinking with edge/cloud computing applications.

Application Service Provider/Developer (ASP/ASD): These are the application developers and providers who offer an application to service consumers. They provide the IoT with the pre-configuration required as well as the application components. They should provide the Application Graph to the edge/cloud orchestration platform, as well as any additional information required to correctly orchestrate and automate the lifecycle of the different parts of the distributed application. This stakeholder might be further composed of two distinct actors, the Application Service Developer (ASD), which develops part or the totality of a distributed application, and the Application Service Provider (ASP) which uses assets from the application developer and of their own to create a consumer.

IoT devices vendors: corresponds to vendors of IoT devices that are interested to support interoperability aspects for their products, including protocol and semantic interoperability.

Application/Service Consumer: end-users of the distributed applications offered by an edge/cloud orchestration platform. Their primary role is to access and utilize these distributed applications to meet their specific needs and objectives. Application/Service consumers expect

	a seamless experience with high-quality services, minimal disruptions, and a user-friendly interface.
Concerns of stakeholders	<ul style="list-style-type: none"> What are the implications of the concept of the Virtual Object in terms of management of IoT infrastructure and interaction with edge/cloud computing applications? How can heterogeneity in terms of communication and semantic protocols be tackled? There is a need for open and interoperable solutions. How can convergence aspects with edge/cloud computing applications be tackled? The VOs should be interoperable with application graphs. The concept of Digital Twin (DT) has to be accommodated within the design of VOSTack. What is the main added value introduced by VOSTack? How can VOSTack be used for innovative new business models?
Expectations on pattern	<p>Solve convergence and interoperability challenges in the IoT domain.</p> <p>Develop IoT applications that are not considered as a silo, but as part of distributed applications offered over resources in the distributed computing continuum.</p> <p>Act as enabler for the development of DTs, offering high degrees of openness and modularity, as well as mechanisms for integration of further functions and mechanisms.</p>

Table 16 describes the pattern.

Table 16 – VOSTack meta-OS pattern

Information	Name	Eclipse Virtual Object Stack (VOSTack) (initially developed in the NEPHELE Horizon Europe project)
	Related patterns	Eclipse aeriOS Meta-OS Pattern
Problem		<p>Even though DTs are emerging in a wide range of use cases, a general-purpose modelling approach, reference architecture, and relevant implementations are lacking.</p> <p>We propose a novel architectural approach to support the development and management of DTs, taking advantage of virtualization and intelligent orchestration mechanisms.</p> <p>We build on existing work on IoT virtualization and the release of an open-source software stack, called Eclipse VOSTack, to address challenges related to IoT interoperability and convergence with edge and cloud computing mechanisms.</p> <p>The proposed approach is open and modular by design, allowing the composition of DTs and Digital Twin Networks (DTNs) that manage and consume information provided by various physical devices, their virtual counterparts referred to as Virtual Objects (VOs), and IoT application components.</p>
Known Context	Specific context	Eclipse VOSTack has stemmed from a European Horizon Europe (HE) project funded by the European commission (HE NEPHELE).
	Related context	<p>Main challenges:</p> <ul style="list-style-type: none"> Address Interoperability in IoT technologies (Protocols, Semantics) Advance IoT software development (address dependencies with IoT hardware; evolve current status in development for IoT, somehow in a “silo” fashion) Manage strict Quality of Service and data processing requirements (e.g., IoT and 6G joint evolution)

		<ul style="list-style-type: none"> Support decentralized Intelligence for management of AI workflows (IoT-Edge interplay)
Solution	Architecture models	<p>The software stack is composed of three layers: (a) the Physical Convergence Layer, (b) the Backend Logic Layer, and (c) the Edge/Cloud Convergence Layer, while it can also support horizontal functionalities that are offered through Sidecars. The software layers of the VOSTack can be seen in Figure 2.</p> <p>The Physical Convergence Layer aims to bridge the gap between the physical and the application layer. Specifically, the VO handles the connection to the IoT device by establishing network connectivity through various communication protocols at:</p> <ul style="list-style-type: none"> the application layer (i.e., MQTT, CoAP, HTTP, Zenoh, WebSockets), the network layer (i.e., IPv4, IPv6), and the transport layer (i.e., TCP, UDP). <p>The Backend Logic Layer extends the functionalities of the IoT devices. The VOSTack can enhance the physical device's functions by generating alerts regarding the device's operational status and data-driven notifications (e.g., a sensor reported a value that exceeds a certain threshold).</p> <p>Storage entities are integrated into the VO to provide efficient data analytics and historical trace analysis. Concerning the interaction with the physical device and the execution of configuration commands, the VO introduces a set of actions that perform specific logic. Moreover, the functionalities of the VO that enable the deployment of modern and cloud-native IoT applications can be split between (i) IoT Device Virtualized Functions and (ii) Generic/Supportive Functions.</p> <p>The Edge/Cloud Convergence Layer bridges the gap between the VOs and the application graphs deployed in the computing continuum. Since the VO is part of one or many application graphs, it interfaces and interacts with various other entities (VOs, cVOs, or application components) and applications.</p> <p>Similar to the protocols used for connecting with the physical device, the VO can utilize communication protocols (i.e., MQTT, CoAP, HTTP, Zenoh, WebSockets) to allow other components to communicate and interact with the VO. This allows the physical devices to be exposed and consumed.</p> <p>This layer provides an interface for retrieving data from the device, invoking functions, and receiving notifications in case of certain events while handling multi-tenancy aspects (e.g., race conditions during the execution of an action by two different parties).</p> <p>Moreover, semantic interoperability plays an important role in creating a unified framework that facilitates application deployment in cloud settings where applications use different semantic models (i.e., OMA LwM2M, W3C-WoT, NGSI-LD) to represent their information.</p> <p>Lastly, this layer enables orchestration actions and monitoring capabilities, thus allowing the computing infrastructure to manage the lifecycle of the VO (e.g., start, stop, restart, destroy) along with its elasticity and migration.</p> <p>The VO is also deployed along with virtualized functions, namely Sidecars. The VO can be considered a microservice that interacts with application components and physical IoT devices to form application graphs in the context of complex DTNs.</p>

		<div><div><div><div>Orchestration</div><div>Monitoring</div><div>Scaling</div><div>Multi-Tenancy</div></div><div><div>Semantic Interoperability</div><div>OMA LwM2M</div><div>W3C WoT</div><div>NGSI-LD</div></div></div><div>Edge/Cloud Convergence Layer</div><div><div><div>Security</div><div>Custom Functions</div><div>Time Sensitive Networking</div><div>Software Defined Networking</div></div><div>Sidecars</div></div><div><div><div>Databases</div><div>InfluxDB</div><div>SQLite</div></div><div><div>Functions</div><div>Healthcheck</div><div>Notification</div><div>Telemetry</div><div>Alerts</div></div><div><div>Device Intelligence</div><div>Task Offloading</div><div>CEP</div><div>TinyML</div><div>Actions</div></div></div><div>Backend Logic Layer</div><div><div><div>Security</div><div>Basic</div><div>Token</div><div>OIDC4VP</div></div><div><div>Protocols</div><div>HTTP</div><div>MQTT</div><div>CoAP</div></div><div><div>Devices</div><div></div><div></div><div></div><div></div></div></div><div>Physical Convergence Layer</div><div><div>VO Descriptor</div></div></div>
Examples	The Eclipse VOSTack has been used for the development of a set of VOs, cVOs and application graphs in the NEPHELE HE project. The considered domains include energy management in smart buildings, logistic operations in ports, emergency response scenarios, and remote healthcare scenarios.	
Rationale for the pattern	Address interoperability and convergence aspects of IoT technologies with edge/cloud computing technologies. Offer a skeleton for the modular, open and extensible development of DTs and DTNs.	
Guidance	Project website: https://projects.eclipse.org/projects/iot.vostack Documentation: https://netmode.gitlab.io/vo-wot/index.html	

4 Conclusion and next steps

This report reflects the common finding of a wealth of EU research projects.

Cloud-edge-IoT (CEI) assets are becoming a reality that needs an ecosystem perspective. As stated on [AIOTI ontology manifesto](#),

“the complexity of ICT systems is raising increasing concerns”, as “such systems involve enhancements, autonomy, updates and reconfigurations at a scale that is unprecedented today. Such systems can be composed of multiple organisations, multiple application domains, multiple technologies, multiple lifecycle phases, multiple description needs, and multiple interoperability points”. CEI assets can reflect this multiplicity.

Therefore, an CEI asset management framework is needed which should leverage existing standards on asset management, and on cloud-edge-IoT computing.

The report further describes eight CEI architecture patterns, following the pattern template provided in ISO/IEC 30141 (IoT reference architecture). All the pattern descriptions show the following:

- The descriptions include use case and solution description which should be decoupled further so that the essence of a pattern is more visible.
- The patterns also relate to other patterns some of them have not been described yet as a pattern:
 - The RESONANCE pattern refers to 3 other patterns (SIF, SGAM, IEC 62746-4),
 - The PARMENIDES pattern refers to 3 patterns (SGAM, SHBIRA, ISO/IEC 30141 - IoT reference architecture),
 - The ECLIPSE-DIGITAL pattern refers to 4 patterns (SIF, SGAM, CEED, DSSC). Note that CEEDS is a specialization of DSSC,
 - The HEDGE-IOT pattern refers to 4 patterns (SGAM, CEED, DSSC, Hedge-IoT dataspace)
 - The HERITWIN pattern lists many aspects such as ISO/IEC 30141, CEI asset management, W2C web of things device abstraction.
 - The aeriOS pattern and the VoStack pattern mention each other.

The following steps are recommended:

- Collect the rationale and contributions that can help create a standard in ISO/IEC JTC1/SC41 on the management of CEI assets.
- Further improve the description of patterns to capture the essence, i.e. decouple the foundational features from implementation dependent aspects.
- Help identify the requirements for a sustainable pattern repository that enable the standardization and reusability of patterns. This includes in particular the management of dependent patterns.

About this Report

About the contributors

This work was performed within the high-level architecture task force of the AIOTI working group on standardisation. We would like to thank the following contributors:

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- Antonio Kung, Trialog, report editor.
- Asbjörn Hovstö, Hafenstrom.
- Bjoern Godager, NTNU.
- Cécile Rabrait, Trialog.
- Diana Jimenez, Trialog.
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About [AIOTI](#)

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

About [CEI-Sphere](#)

Cloud, edge and IoT technologies are evolving rapidly. However, interoperability, market maturity and robust ecosystems remain key challenges. With this in mind, the EU-funded CEI-Sphere project aims to create a cohesive, open ecosystem to support large-scale pilots (LSPs) in Cloud-Edge-IoT, focusing on projects from the CL4-2024-DATA-01-03 call. CEI-Sphere will deliver a high-level reference architecture, market analysis reports and a catalogue of use cases. By addressing interoperability, scalability and security, CEI-Sphere aims to fast-track results, leverage open source communities, foster international standards and create synergies across CEI stakeholders. A consortium, including SMEs, companies and industry associations will work to maximise impact of associated large-scale pilot action and promote open calls towards a vibrant ecosystem around cloud edge IoT computing.

CEI-Sphere is a project funded by the European Union under Grant agreement ID: 101189683.

About [O-CEI](#)

Through the spread of digitalisation, the Internet of things (IoT) has become increasingly crucial to the everyday functioning of logistics chains, infrastructure, business and more, driving novel solutions and innovations that benefit a wide range of services and sectors. In this context, the EU-funded O-CEI project aims to enhance Europe's competitiveness and strategic autonomy in this sector, recognising the global significance of open cloud-edge IoT. It plans to achieve this by supporting eight pilots in key sectors through the introduction of novel technologies, frameworks and improved data sharing, leveraging shared developments to strengthen each pilot and maximise its potential.

O-CEI is a project funded by the European Union under Grant agreement ID: 101189589.

About [RESONANCE](#)

Recent changes and innovations in the energy sector have showcased the possible benefits of utilising demand-side flexibility management (DSFM) solutions for improving overall efficiency. Customer energy managers and resource managers are crucial tools for this purpose, being efficient, practical and promising DSFM solutions. The EU-funded RESONANCE project will integrate DSFM in Europe by developing a revolutionary software framework that will allow for the easy and fast incorporation of customer energy manager and resource manager solutions. To achieve this, it will cooperate with stakeholders and sector actors to encourage the adoption of customer energy managers and showcase their lower costs and work requirements.

RESONANCE is a project funded by the European Union under Grant agreement ID: 101096200.

About [PARMENIDES](#)

The rise of new technologies in the energy system transition is resulting in the unavoidable fragmentation of existing platforms, protocols and standards. Despite these challenges, cross-platform and cross-domain interoperability must be ensured. The EU-funded PARMENIDES project will focus on ontologies that provide an opportunity to address cross-platform interoperability. Specifically, it will extend existing ontologies to develop a new ontology and provide a knowledge base focusing on electricity and heating for buildings, customers and energy communities. The project will focus on hybrid energy storage systems, supporting various use cases. PARMENIDES will develop a new generation of innovative energy management systems capable of using ontology as a knowledge base and demonstrate it in pilots in Austria and Sweden.

PARMENIDES is a project funded by the European Union under Grant agreement ID: 101096453.

About [HEDGE-IoT](#)

As our world increasingly relies on renewable energy sources, energy systems face unprecedented challenges, and there's a need for new approaches and thorough transformation in common practices. The EU-funded HEDGE-IoT project aims to revolutionise the digitalisation of European energy systems by exploiting advantages of IoT technologies, deployed at different levels of the power systems, through an interoperable and standardised digital framework. Bridging the edge-cloud continuum through computational orchestration and federated learning traits lies at the centre of the project's activities. The HEDGE-IoT ecosystem will pave the way towards increased grid flexibility, enhanced hosting capacity of renewable energy sources, and a more robust and resilient power system operation. The overall aim is to expand market opportunities and promote advancements in IoT standardisation.

HEDGE-IoT is a project funded by the European Union under Grant agreement ID: 101136216.

About [HERITWIN](#)

HERITWIN is a Horizon Europe cultural heritage digital twin project that validates ECCCH-aligned workflows through five pilots across Europe.

It combines cultural digital twins, semantic interoperability, XR, AI-assisted enrichment, preparedness modelling and controlled data sharing to support heritage preservation, access and reuse. In this report, HERITWIN contributes a Cloud-Edge-IoT asset pattern for cultural heritage, showing how physical sites, digital representations, metadata pipelines, monitoring data, access-control rules and validation evidence can be managed as reusable CEI assets.

HERITWIN is a project under negotiation with the European Union.

About [CTAG](#)

CTAG is a private and independent technology centre, whose strategy is oriented towards scientific-technical excellence, technological specialisation and internationalisation in the automotive, transport and mobility industry.

The CTAG team is our greatest asset. We offer you the opportunity to develop your skills and expand your know-how in the field of automotive and R&D&I.

About [aeRIOS](#)

Eclipse aeriOS inherits from a part of the results of the Horizon Europe project [aerOS](#).

Eclipse aeriOS provides a Meta Operating System that works across the entire computing spectrum, from IoT devices and edge systems to the cloud. It creates a single environment where you can deploy and manage containerized workloads across different systems and organizations, based on your specific needs.

Accessible through both a user interface and an API, Eclipse aeriOS brings together several key features into one platform. These include access control, performance comparison, distributed computing, continuous monitoring, and automated processes at the edge.

aerOS is a project funded by the European Union under Grant agreement ID: 101069732.

About [VOStack](#)

Eclipse VOSTack inherits from a part of the results of the Horizon Europe project [Nephele](#).

The Eclipse VOSTack project delivers a multi-layer software framework that virtualizes IoT devices into interoperable Virtual Objects, enabling standardized management, semantic abstraction, service composition, and seamless integration with edge/cloud technologies.

Eclipse VOSTack is aligned with the W3C Web of Things Standard.

A Virtual Object (VO) is a virtual counterpart of an IoT device. It provides abstractions for managing any type of IoT device while augmenting the supported functionalities through a multi-layer software stack, called VO Stack.

Nephele is a project funded by the European Union under Grant agreement ID: 645212.