Grant Agreement No.: 101070030

Call: HORIZON-CL4-2021-DATA-01

Topic: HORIZON-CL4-2021-DATA-01-07

Type of action: HORIZON-CSA

D2.2 OPENCONTINUUM LANDSCAPE V2 AND RECOMMENDATIONS

Revision: v.0.4

Work package	WP 2
Task	Task 2.2, Task 2.3 and Task 2.4
Due date	31/08/2024
Submission date	17/09/2024
Deliverable lead	ATOS
Version	0.4
Authors	Lara López (ATOS)
Reviewers	Albert Seubers (MARTEL), Antonio Kung (TRIALOG)

Abstract	This document presents the work done in WP2 of OpenContinuum and TF3 of EUCEI developing a common taxonomy and a reference architecture for the continuum, as well as documents the results already published within the website in form of white and/or position papers.
Keywords	Landscape, architecture, taxonomy, recommendations

Document Revision History

Version	Date	Description of change	List of contributor(s)
v0.1	23/05/2024	Initial ToC and assignments	Lara López (ATOS)
v0.2	22/07/2024	Executive Summary and Section 1	Lara López (ATOS)
v0.3	29/07/2024	Section 2 and Annexes	Lara López (ATOS)
v0.4	16/09/2024	All missing sections	Lara López (ATOS)

Disclaimer

Copyright Notice

Project co-funded by the European Commission in the Horizon Europe Programme		
Nature of the deliverable:	**R**	
Dissemination Level		
PU	Public, fully open, e.g. web	**X**
SEN	Sensitive, limited under the conditions of the Grant Agreement	
Classified R-UE/ EU-R	EU RESTRICTED under the Commission Decision No2015/ 444	
Classified C-UE/ EU-C	EU CONFIDENTIAL under the Commission Decision No2015/ 444	
Classified S-UE/ EU-S	EU SECRET under the Commission Decision No2015/ 444	

Funded by Horizon Europe Framework Programme of the European Union

***** R: Document, report (excluding the periodic and final reports)**

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

DATA: Data sets, microdata, etc

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

SECURITY: Deliverables related to security issues

OTHER: Software, technical diagram, algorithms, models, etc.

Funded by Horizon Europe
Framework Programme of the European Union

EXECUTIVE SUMMARY

The emergence of needs for homogenised solutions integrating the three pillars of the continuum: cloud, edge and IoT paradigms, has risen the lack of full-stack technologies for operating services across it. The work done during the last two years and all the activities performed in order to develop a common point of view from the research supply side are as follows:

- Taxonomy for the continuum: first of all, it is of paramount importance to have a common language for all actors in order to make sure there are no gaps when discussing about technology. Thus, a homogenised taxonomy, gathering references from existing taxonomies, glossaries and standards, has been developed for the continuum, while including new terms arose specifically for it.
- Building blocks, requirements and functionalities for the continuum: once the language to be used was clear, a set of technologies, requirements and minimum functionalities was identified to be used as the basis for developing a reference architecture that can be used and further extended according to specific needs.
- Reference architecture for the continuum: this architecture includes the work done by more than 40 different research projects working on different aspects of the continuum.
- Solution architectures for the continuum: this document contains the architectures designed by different research projects addressing some of the requirements, or implementing functionalities, previously identified as part of the work done to solve their use cases, needs.
- Landscape of technical assets: graphical representation of research assets, open source projects and commercial products implementing different functionalities identified within the architecture development.
- Methodology for evaluating research results: methodology developed within the scope of the project in order to provide further recommendations for improving the impact of the technical solutions, as well as identifying gaps in those areas where there is still room for further research or where more support is needed to maximise the impact of European research.
- Future research challenges: Set of challenges identified during the design of the reference architecture that cannot be addressed with the current state of the art of the technology.

This document contains the process followed for achieving the abovementioned results, as well as the summary of the key findings. Furthermore, this work will be continued as part of the liaison with ISO/IEC to standardise the taxonomy and building blocks developed.

Funded by Horizon Europe Framework Programme of the European Union

TABLE OF CONTENTS

Funded by Horizon Europe Framework Programme of the European Union

LIST OF FIGURES

Funded by Horizon Europe Framework Programme of the European Union

ABBREVIATIONS

AI	Artificial Intelligence
AIoT	Artificial Intelligence of Things
API	Application Programming Interface
CPU	Central Processing Unit
EUCEI	EU Cloud Edge IoT
IAM	Identity and Access Management
LLM	Large-Language Model
SEE	Secure Execution Environment
SOAR	Security Orchestration, Automation and Response
TEE	Trusted Execution Environment
TF	Task Force
TRL	Technology Readiness Level
TTPs	Tactics, Techniques and Procedures
WP	Work Package
ZTA	Zero Trust Architecture

Funded by Horizon Europe Framework Programme of the European Union

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The work presented in this document contains the description of the activities performed in the context of WP2 'MAP & ACT', as well as those corresponding to TF3 Architecture. The objectives of both are as follows:

WP2:

- To define a conceptual framework for the cloud-edge-IoT landscape.
- To map relevant actors in the cloud-edge-IoT landscape and engage them in the activities (looking for relevance, openness, diversity, representativeness of the community and its results).
- To support the analysis of the collected information.
- To provide strategic recommendations to support the EU digital autonomy in the computing continuum.
- To drive forward those actions by "acting/doing" beyond the pure analysis.

TF3:

- To enable the architectural discussions among projects in the area of IoT/Edge and Cloud to create a continuum.
- To identify thematic areas and building blocks.
- To understand the contribution of each project to the thematic areas, allowing the identification of cross-project synergies.

1.2 STRUCTURE OF THE DOCUMENT

The document is structured into 5 main sections:

- **Section 1:** this section contains the objectives accomplished during the project lifespan, as well as the structured activities performed.
- **Section 2:** it presents the work done in the context of WP2 and TF3, as well as their overlaps.
- **Section 3:** it contains the final methodology followed to design the reference architecture for the continuum and the available results.
- **Section 4:** as a preliminary step for the development of the graphical representation of the landscape, this section introduces the methodology followed to gather the assets as well as the analysis of the inputs collected at research, open source and commercial level to make it accessible for external readers.

Funded by Horizon Europe Framework Programme of the European Union

- **Section 5:** based on the results of the previous activities, this section contains a set of recommendations for both, research projects and funding bodies to maximise the impact of results. Additionally, next steps are also included here.

Funded by Horizon Europe Framework Programme of the European Union

2 SUMMARY OF THE WORK DONE

One of the main goals of OpenContinuum is to provide a common view of the available results of European research project. This work is twofold:

i) Within the context of the own project, there is a need of understanding the current state of the art and homogenising the information available.
ii) While from the EUCloudEdgeIoT initiative, it is of paramount importance to provide a unified view that can be further reused by future research projects or any other interested stakeholder.

The following subsections contains the summary of the activities performed, as well as the results produced.

2.1 WITHIN OPENCONTINUUM (WP2)

The main goal of WP2 is to produce a common language for all European research projects addressing challenges in any topic referred to the Continuum, as well as to identify challenges, gaps and available results related to them.

In this sense, the work during the second period has focused into three main aspects:

1. Cooperate with ongoing research projects to define a common glossary, based on the three pillars of the continuum (cloud, edge and IoT) and the eight building blocks (security and privacy, trust and reputation, data management, resource management, orchestration, network, monitoring and observability, and artificial intelligence) identified during the first period and foster its adoption.
2. Interact with different stakeholders of the value chain and develop a conceptual framework to evaluate available results, measuring their impact and providing recommendations, as well as validate them in order to provide a set of recommendations for both, research projects implementing results and funding bodies to support them while maximising their impact.
3. Produce an online landscape showing the most mature research assets, as well as other open source projects and commercial products that can be adopted to implement some of the needed functionalities to operate applications within the continuum.

2.2 WITHIN EUCEI (TF3)

WP2 work has been complemented with the technical work performed within the scope of TF3 bearing in mind that everything is fully aligned to create an understandable story line. The work can be summarised as follows:

1. Convert building blocks into a usable reference architecture, identifying the main functionalities and requirements, as well as the minimum components integrating them so it can be further extended based on specific implementation needs.

Funded by Horizon Europe Framework Programme of the European Union

2. Standardised results so they can be further adopted not only by future research projects but also by other initiatives.
3. Identify gaps to provide a set of research challenges, related to the continuum, that cannot be addressed due to the maturity of the available technologies.

Funded by Horizon Europe Framework Programme of the European Union

3 REFERENCE ARCHITECTURE

This section contains the results of the work performed during the last year of the project in order to develop a reference architecture for the continuum, based on research results.

3.1 METHODOLOGY

The main goal to develop a reference architecture for the Continuum gathering inputs from ongoing research projects addressing current challenges. In order to do so, the following methodology has been applied to facilitate discussions and enrich results:

ITERATION-1: Homogenised terminology

Before starting technical discussions, it is important to take into account that different terminology with the same meaning can be applied to different stages of the continuum. Thus, the first step is to homogenise the terminology to be applied ensuring that all participants use the same terms referring to the same concepts.

An initial glossary, to be extended to a taxonomy, it is developed as the key activity.

ITERATION-2: Building blocks

Once the terminology is clear and agreed by all participants, it is important to identify the different topics that need to be defined in order to design an architecture for the continuum. Each of these topics is then converted into a building block representing the set of requirements that must be satisfied.

ITERATION-3: Functional view

Once the requirements are elicited, it is time to analyse them and determine what are mandatory, nice-to-have or out-of-scope. With this categorization already in place, a minimum set of functionalities must be identified to address them. These functionalities and their relationships are properly described, and graphically represented, within this iteration.

ITERATION-4: Compositional view

This is the final step in defining a reference architecture, completely technology agnostic. Functionalities are clustered within different technical components that will be responsible for their implementation. In addition, all projects participating in the definition will also provide their solution architecture, highlighting the different implementation possibilities.

ITERATION-5: Implementation and future research challenges

The work performed will be further developed to produce a document ready to be submitted to a standardisation body, properly acknowledging the contributions from all participants.

Additionally, different technological gaps were identified within the architecture definition based on the current state-of-the-art technologies and projects' research. These gaps are collected and analysed to properly identify future research challenges not covered by current project results (see Annex 4).

Funded by Horizon Europe Framework Programme of the European Union

3.2 ACTIVITIES PERFORMED

This section presents all the activities performed and the main outcomes from each of them.

1st Workshop

The first workshop was organised with the presence of representatives from the different MetaOS projects, as they are the only ones operating across all pillars of a continuum environment.

The TF3 leader presented a set of building blocks representing the main topics to be covered in order to implement an architecture for the continuum, as well as an initial set of terms that must be incorporated within each of them.

During the workshop, all participants discussed the feasibility of the topics as well as the minimum set of terms to be included (and are not covered by current taxonomies).

The results of this workshop were used as a basis for the preparation of the second one.

2nd Workshop

The second workshop was open to all TF3 participants. As in the previous one, TF3 presented the set of building blocks and the categorization of the terms in each of the previously identified pillars: cloud, edge and IoT.

Due to the number of participants, the work was split into two working groups who worked in parallel to present their conclusions later on.

Both groups worked on the elaboration of the final list of building blocks for the continuum, missing terms for having a common taxonomy and some basic functionalities needed.

Architecture design KO

After consolidating the results of the previous workshops, an additional telco was organised with the projects interested in participating in the development of a reference architecture for the continuum.

In order to facilitate the debate and ensure that all topics are developed sufficiently, 8 working groups were established:

WG1 Security & Privacy: security is a transversal challenge to be addressed while operating data across the continuum. The main goal of this working group was to properly identify all security considerations that must be taken into account.

WG2 Trust & Reputation: beyond security, it is needed to implement the necessary mechanisms to measure the trust and reputation levels of users, providers and any additional sources. This working group therefore identified the mechanisms to be implemented.

WG3 Data management: this is basic not only for application analytics but also for taking informed decisions for, e.g., the best location to perform an action. So, this working group took care of the proper data management at system and application level.

WG4 Resource management: infrastructure management is important in any cloud/edge architecture. However, when incorporating IoT the number of devices to be managed grows exponentially. This working group was in charge of identifying the functionalities needed to properly manage all of them.

WG5 Orchestration: the core of the architecture relies on the orchestration of services, applications or even functions, as well as network resources or devices. Within the activities performed in this work group the proper orchestration of services and applications can be found, as can the integration with other related working groups in charge of orchestrating different resources.

WG6 Network: in the transition from cloud/edge to IoT, network constraints are even more relevant. Thus, this working group debated on all aspects related to network management.

WG7 Monitoring & Observability: QoS/QoE are beyond the proper functioning of the system. This working group was in charge of monitoring the system health and provide the needed information to other working groups.

WG8 Artificial Intelligence: artificial intelligence has been a transversal topic to all working groups, as it can be incorporated as a functionality in any of them. Additionally, this working group focused also on the execution and deployment of different models.

After this meeting, all projects appointed their representatives to participate in the different working groups according to the topics addressed by the project and their own interest in different challenges.

Periodic telcos for designing the Functional view

A set of weekly telcos per working group was held to allow project representatives to debate about the minimum set of functionalities that are needed to implement a proper reference architecture for the continuum.

All meetings were organised by OpenContinuum and moderated by its representatives. Additionally, some of the working groups were led by a representative of one of the projects involved in TF3, while others were led by the TF3 leader.

During the meetings, different documents were produced to collect feedback from all participants, with the next meeting building on the results of the previous one.

The documents were available in a TF3 folder shared with all participants.

Integration meetings

There were two rounds of telcos for designing the functional view. These were followed by additional telcos for presenting and integrating the results of each working group were held.

These meetings were organised and moderated by the TF3 leader, and each working group leader played a crucial role in presenting the results of the groups. Additional contributions from other participants were also encouraged.

Funded by Horizon Europe Framework Programme of the European Union

During the meetings, in addition to the presentation of results, several discussions were held to identify the requirements from other working groups that will influence the final functional view of the integrated architecture.

Periodic telcos for designing the Compositional view

Once the functional view was consolidated, a new round of telcos started to design the compositional view, i.e., the minimum set of components to be implemented covering the functionalities identified earlier.

The meetings were organised in the same way as those followed for the design of the functional view.

Integration meetings

As it happened with the previous set of telcos, a number of integration meetings were held in order to design a common view for the final reference architecture.

3.3 RESULTS

There are several three main results, already available in the EUCEI website, and summarized here:

Taxonomy and building blocks

A faceted taxonomy has been developed following the Taxonomy Best Practice Framework [1]. This type of taxonomy was selected due to the complexity of representing the continuum. Thus, the multilayered taxonomy consists of three pillars: Cloud, Edge and IoT, plus an additional one for those terms which do not fit in a single one. This is complemented with eight categories representing the technologies for the continuum: Security & Privacy, Trust & Reputation, Data management, Resource management, Orchestration, Network, Monitoring & Observability, and Artificial Intelligence.

An initial set of terms was proposed, as well as the inclusion of other well-known glossaries and standardised taxonomies, such as NIST taxonomy for cloud [2], LF glossary for edge [3] or some ISO standards for IoT.

All projects were invited to contribute to the identification of new terms, according to their background, that belong only to the continuum.

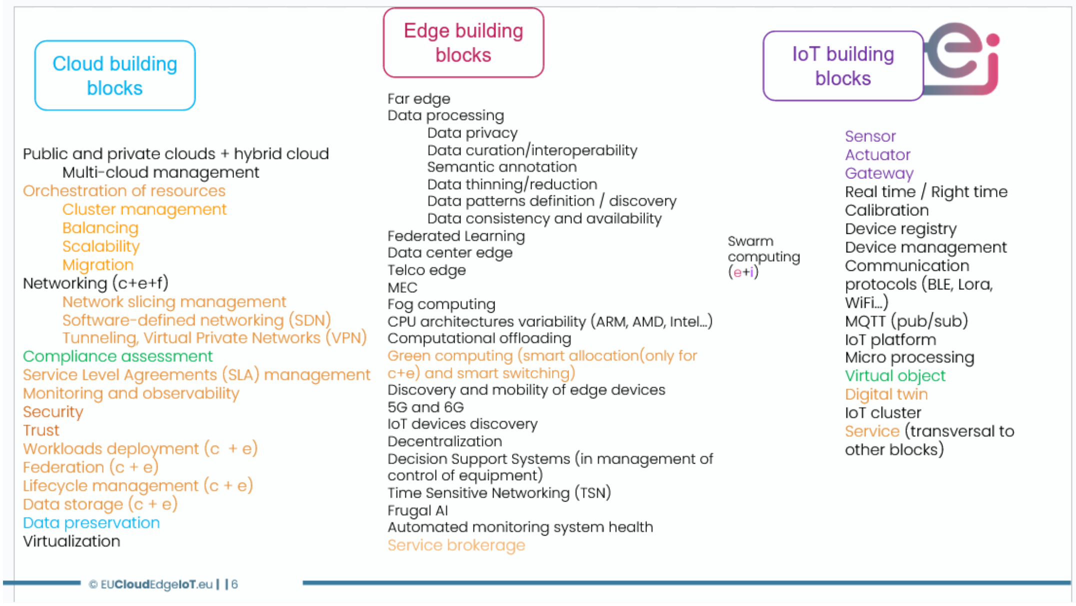


FIGURE 1: RESULTS OF THE FIRST TAXONOMY WORKSHOP

Here the summary of the results of the functional view definition, as they can be seen in the corresponding white paper, available at the website [4].

Security & Privacy

Security is a transversal challenge to be addressed while operating data across the continuum. The main goal is to properly identify all security considerations that must be taken into account. At the same time, privacy is a mandatory requirement to address needs and requirements from the legislative framework. So, complementing the main goal, a set of needed functionalities has been also identified to address privacy requirements.

Funded by Horizon Europe Framework Programme of the European Union

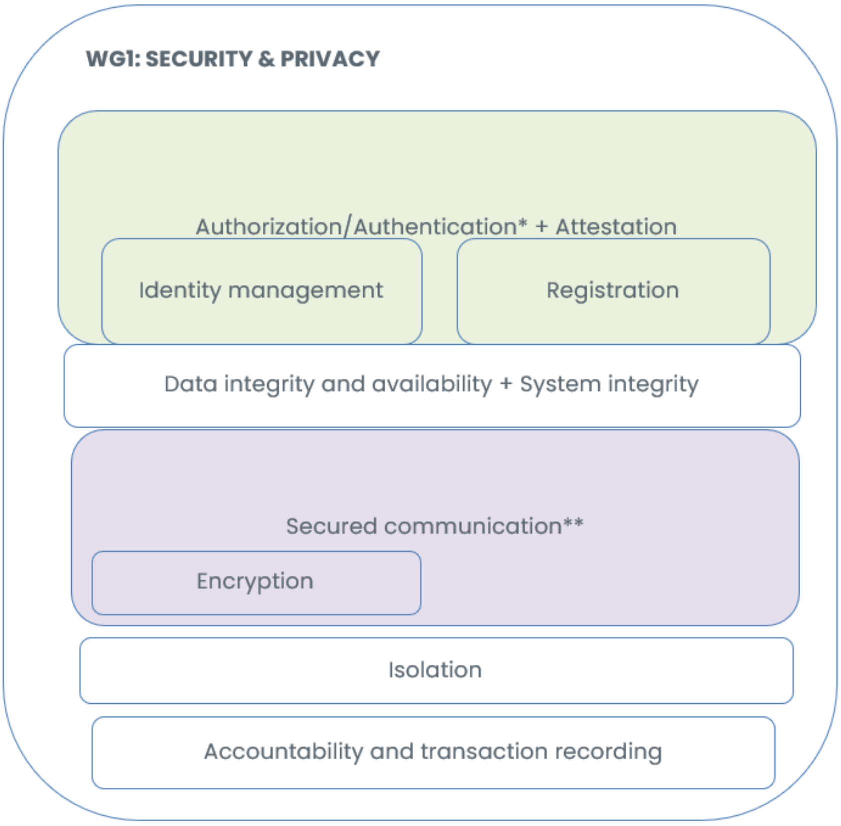


FIGURE 2: BUILDING BLOCK 1

***** Needed for all building blocks***

***** Mandatory to ensure security between components***

The figure shows the functionalities needed to ensure proper security and privacy management within the architecture, including those that must be included in the definition of functionalities from other building blocks.

Based on this, the following list defines each of the identified functionalities:

- **Authorization/Authentication + Attestation:** in charge of allowing the access to the system to all users according to a predefined role, plus ensuring all agents are allowed to be part of the system. This information must be spread to all building blocks:
  - *Registry:* catalogue of users and resources and their role within the system.
  - *Identity (and access) management:* to ensure only allowed users can access the system.
- **Data integrity and availability + System integrity:** ensuring all data is trustable, accessible and coherent. As well as for the system. This includes a dedicated chapter for safety (to be implemented under demand) for specific use cases.
- **Secured communication:** Needed to ensure the security and safeness of all communications between the different components (needed for all building blocks).
  - *Encryption:* of data transmitted during communication.
- **Isolation:** to minimize threats based on, e.g., Trusted Execution Environments (TEEs) on the different hardware architectures (Intel SGX, ARM Trustzone, etc.).

Funded by Horizon Europe Framework Programme of the European Union

- **Accountability and transaction recording:** only for those implementations that involve any economic transaction (blockchain-related).

Trust & Reputation

Beyond security, it is needed to implement the necessary mechanisms to measure the trust and reputation levels of the users, providers and any additional source.

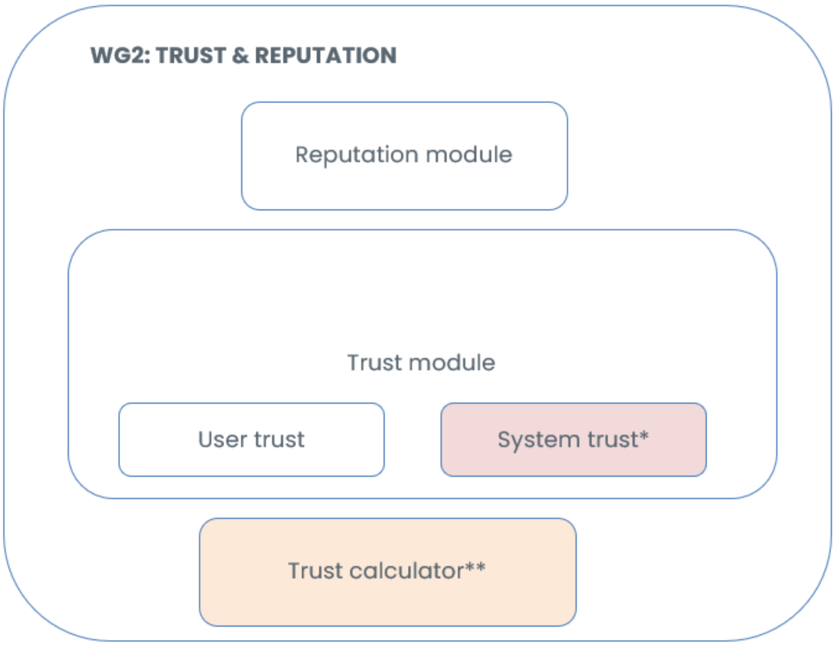


FIGURE 3: BUILDING BLOCK 2

Needed for building block 1 (Security & Privacy)

****Distributed among nodes***

- **Trust calculator:** distributed among nodes to collect specific information of a given node. This information will be shared with the Trust module or exposed to the user if needed.
- **Trust module:** in charge of calculating the trust level of the system or the users and sharing this information with the user.
  - *User trust:* measures the trust level of a user based on his/her actions.
  - *System trust:* measures the trust level of the system. Initially based on the available information from the provider, to be updated later on with the results from the trust calculator. This information is also shared with building block 1 (Security & Privacy) with regards to the system trustworthiness to be included as an additional security consideration within the system integrity evaluation.
- **Reputation:** measures the reputation level of a given provider and makes suggestions to the user in order to select one or another for his/her deployment. More related to Quality of Experience (QoE).

Data management

Funded by Horizon Europe Framework Programme of the European Union

Data management is basic, not only for application analytics, but also for taking informed decisions, e.g., the best location to perform an action. Thus, it is important to properly define the data management at system and application level.

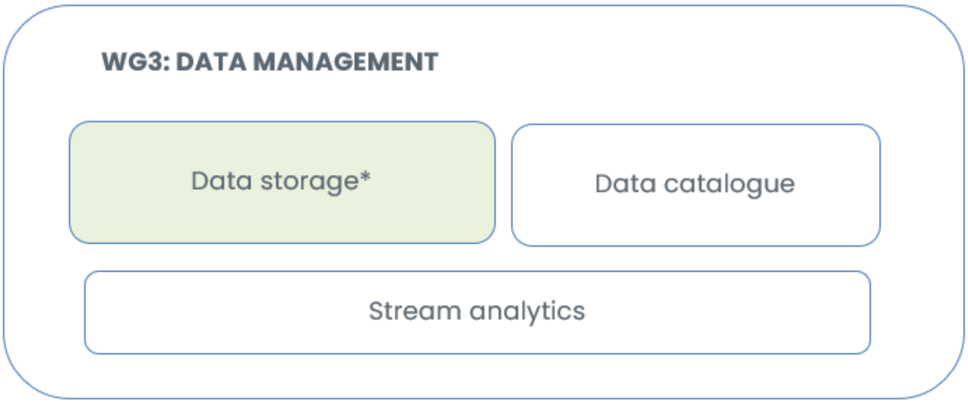


FIGURE 4: BUILDING BLOCK 3

Needed for all building blocks

- **Data storage:** common to all building blocks and in different formats.
- **Data catalogue:** registers all data stored within the system so it is available for different components.
- **Stream analytics:** performed after request.

Resource management

Infrastructure management is important in any cloud/edge architecture, however, when incorporating IoT the number of devices to be managed grows exponentially. So, the main goal is identifying the functionalities needed to properly manage all of them.

Funded by Horizon Europe Framework Programme of the European Union

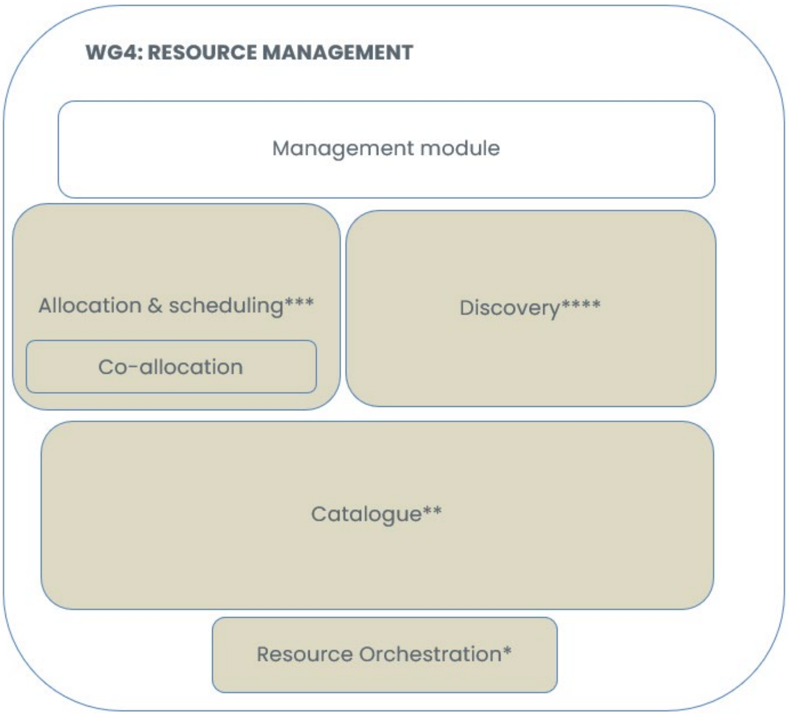


FIGURE 5: BUILDING BLOCK 4

Linked to low level orchestration (building block 5 - Orchestration)

*****Linked to storage and analytics (building block 3 – Data management)***

******Linked to scheduling (building block 8 – Artificial Intelligence) and federation (building block 5 - Orchestration)***

*******Linked to scheduling (building block 8 – Artificial Intelligence) and monitoring (building block 7 – Monitoring & Observability)***

- **Management module:** smart decision maker for resource management.
- **Allocation & scheduling:** collects information about resource availability and sets up the cluster of needed resources.
    - *Co-allocation:* allocate resources from different providers.
- **Discovery:** looks for those resources which fulfil the requirements established by the user or the application.
- **Catalogue:** contains the information about all the resources registered within the system.
- **Resource orchestration:** provides the information about the resource deployment scheme.

Orchestration

The core of the architecture relies on the orchestration of services, applications or even functions, as well as network resources or devices. Thus, it is important to identify how to

Funded by Horizon Europe Framework Programme of the European Union

properly perform the orchestration of services and applications, and the integration with other related blocks in charge or orchestrating different resources (devices, network or artificial intelligence models, among others).

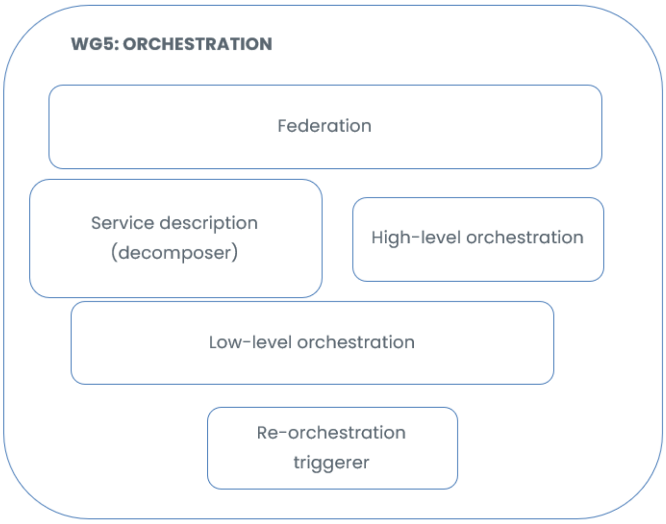


FIGURE 6: BUILDING BLOCK 5

- **Federation:** manages cloud/edge, combined with the resources' information, to ensure the availability of all of them for a given deployment.
- **Service description:** contains the requirements of a given application about deployment needs. This includes day-0 deployment Service Level Agreement (SLA), requirements, and other specific policies as well as service workload specification. This global flow should be understood two-fold: (i) autonomous way, (ii) exposing the information so that it could be leveraged by other components. In the autonomous way, this can be conceived as well in two ways: self-contained, expressed by the user, and the other one is that the application generates dynamically its own requirements. The service description (composer) shall also include the "topology" concerns (e.g., network, ports exposure, relation to other microservices, resources needed - in terms of spot in the continuum, etc.).
- **High-level orchestration:** collects the scheduling recommendations to develop the deployment scheme and sends this information to the low-level orchestrator. In case of rescheduling, based on predictive maintenance, it capitalizes the action again.
- **Low-level orchestration:** orchestrates network, resources and services as needed. In case something is not properly working and needs immediate action, it takes the lead.
- **Re-orchestration triggerer.** A variety of reasons (e.g., overload of resources, predictive maintenance alerts, certain events) that will trigger a re-orchestration request. Also, the reorchestration can happen from a logical point of view, not necessarily coming from specific events.

NOTE: FaaS special case not as same level as Low-level orchestration

Funded by Horizon Europe Framework Programme of the European Union

- **FaaS scheduling:** Part of the low-level orchestration only for specific UCs where functions are involved.
- It might be omitted as an extra box

Specific for FaaS use cases (UCs)

Network

In the transition from cloud/edge to IoT, network constraints are even more relevant.

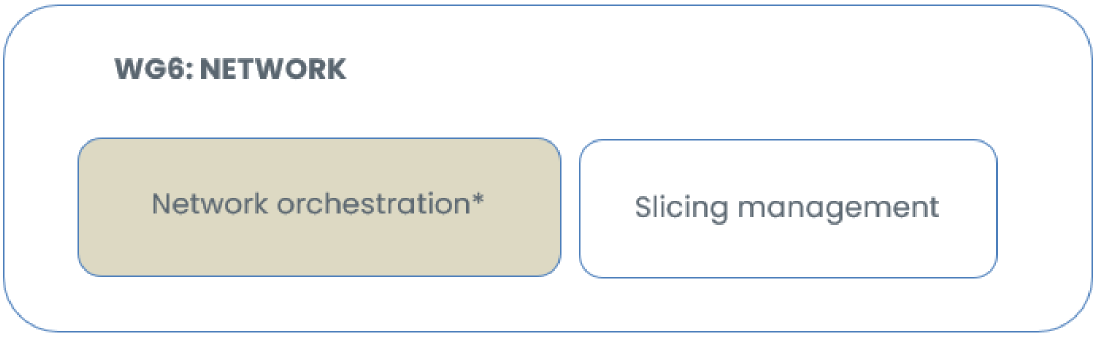


FIGURE 7: BUILDING BLOCK 6

Linked to low level orchestration (building block 5 - Orchestration)

- **Network orchestration:** whenever it is possible (relies on the infrastructure setup).
- **Network slicing:** additional to the orchestration and performed under request.

Funded by Horizon Europe Framework Programme of the European Union

Monitoring & Observability

QoS/QoE are beyond the proper functioning of the system, so it is necessary to monitor the system health and provide the needed information to other blocks.

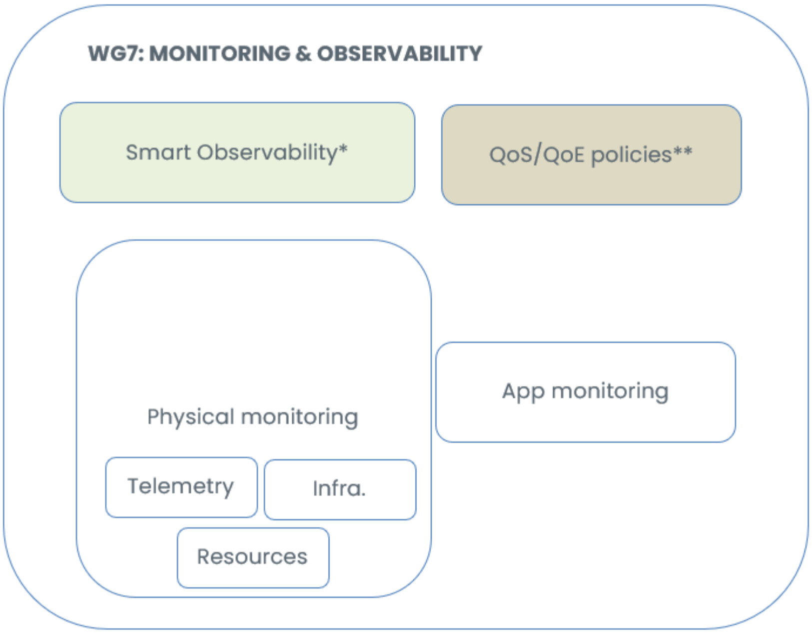


FIGURE 8: BUILDING BLOCK 7

Linked to storage and analytics (building block 3 – Data management). Data exposure to all WGs. And scheduling (building block 8 – Artificial Intelligence) for predictive maintenance.

*****Linked to storage (building block 3 – Data management)***

- **Smart Observability:** collects monitoring information and provides the first analysis together with the Service Level Objects (SLOs) previously defined to inform about any potential event. It establishes different levels of alerts to make the distinction between predictive maintenance and immediate actions.
- **Quality of Service (QoS)/QoE policies:** catalogue of SLOs.
- **Physical monitoring:** in charge of collecting data from the physical layer.
  - **Telemetry monitoring:** monitors the network health.
  - **Infra monitoring:** monitors cloud/edge infrastructure.
  - **Resource monitoring:** monitors IoT devices.
- **App monitoring:** in charge of collecting data about the application status.

Funded by Horizon Europe Framework Programme of the European Union

Artificial Intelligence

Artificial intelligence is a transversal topic to all blocks, as it can be incorporated as a functionality in any of them. Additionally, it also focuses on the execution and deployment of different models.

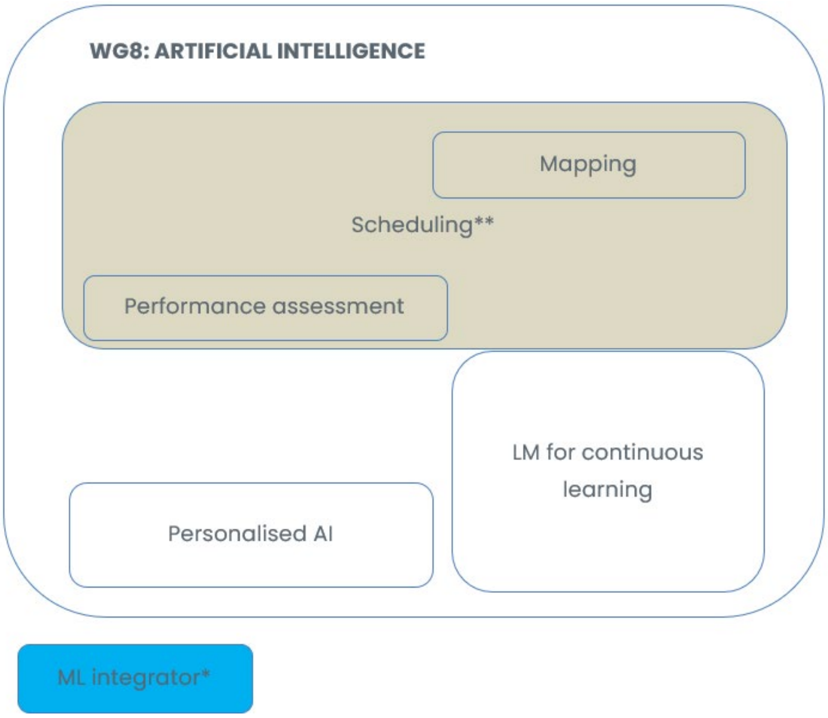


FIGURE 9: BUILDING BLOCK 8

Challenge for future research

*****Linked to high level orchestration and federation (building block 5 - Orchestration) and resource management (building block 4)***

- **Scheduling:** analyses the available information and provides recommendations to support high-level orchestration decision making.
    - *Mapping:* maps the service, or the Artificial Intelligence (AI) algorithm, requirements with the most appropriate physical device for deployment.
    - *Performance assessment:* of an already deployed service or AI algorithm. This information is used for predictive maintenance or directly communicated to the user.
- **Personalised AI:** for specific cases where the user demands dedicated models to be used.
- **Lifecycle Management (LM) for continuous learning:** lifecycle management to allow the involved AI/Machine Learning (ML) to learn during a non-defined time period.
- **ML integrator:** nice to have but not currently supported, in order to allow the combination of different ML algorithms to develop new ones.

Funded by Horizon Europe Framework Programme of the European Union

Compositional view of the Reference Architecture

And finally, the compositional view as it can be seen in the corresponding white paper [5].

Security & Privacy

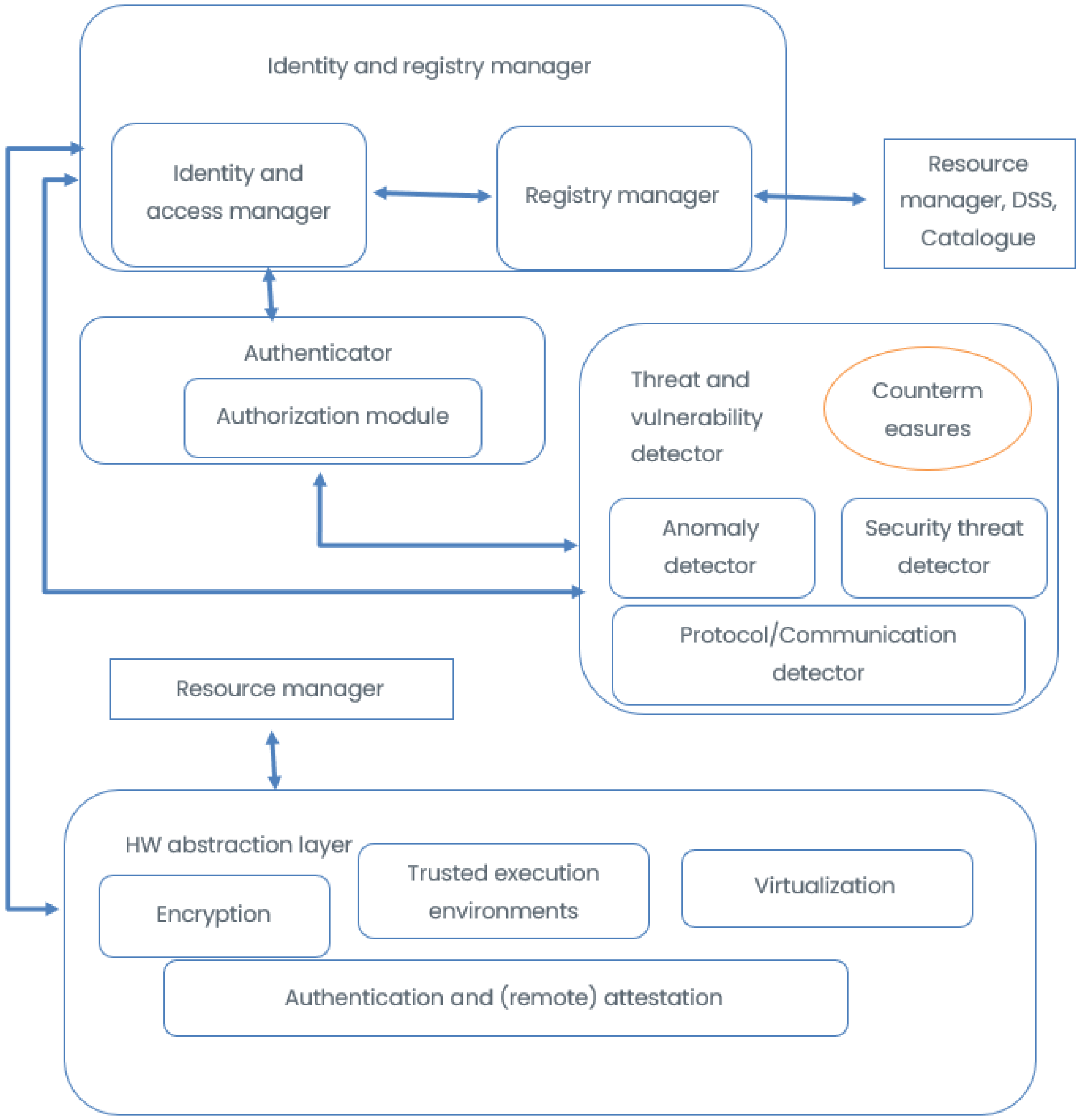


FIGURE 10: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE – SECURITY AND PRIVACY

Common capabilities:

- Identity and registry manager
    - Identity and access manager (for users and HW), using e.g., PUFs and TPMs on hardware level
    - Registry manager
- Authenticator
    - Authorization module

- Threat and vulnerability detector + countermeasures
    - Anomaly detector
    - Security threat detector
    - Protocol/Communication detector (includes network connections)
    - Impact analyser & recommender
- HW abstraction layer (for security)
    - Encryption
    - Trusted execution environments - Connected to Trust Calculator
    - Virtualization
    - (remote) attestation - Connected to auth/authorization module

Optional for specific UCs:

- Secured transactions (blockchain)
- Accounting mechanisms

Specific for safety (related to building block 2 – Trust & Reputation):

- Functional safety
- Network measures for deploying ms in different network instances

Trust & Reputation

Funded by Horizon Europe Framework Programme of the European Union

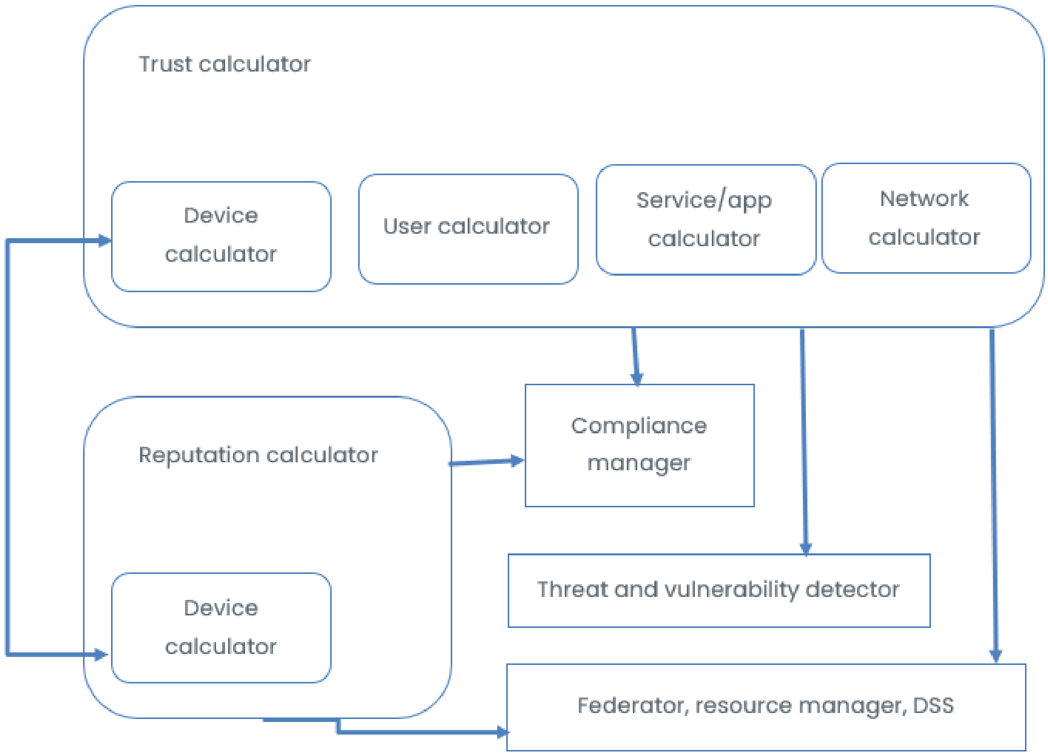


FIGURE 11: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE - TRUST AND REPUTATION

Common capabilities:

- Periodically updated trust score for IoT devices and user trust is needed for security/safety consideration.
- Trust calculator (context-aware - considering parameters from different contexts (e.g., device capabilities, network, app, security…)
    - calculates trust from the device perspective — user perspective — application/service perspective.
    - device trust: HW/SW specifications of the manufacturer (MUD protocol)
        - security capabilities
        - MQTTs or any data brokering protocol.
        - Trust Ranking for recommendation (e.g., TOPSIS, etc.)
            - inform the user about the trust scores of the current devices capable of offering the service requested.
    - network/domain trust: IDS, threat intelligence
    - user trust: user behavior, user reputation
        - no information means assigning the lowest trust score that still allows the user/device to onboard and operate within the system.
- Reputation calculator

Funded by Horizon Europe Framework Programme of the European Union

- HW provider calculator
  - info to be shared with the user for selecting the most appropriate provider.

Funded by Horizon Europe Framework Programme of the European Union

Data management

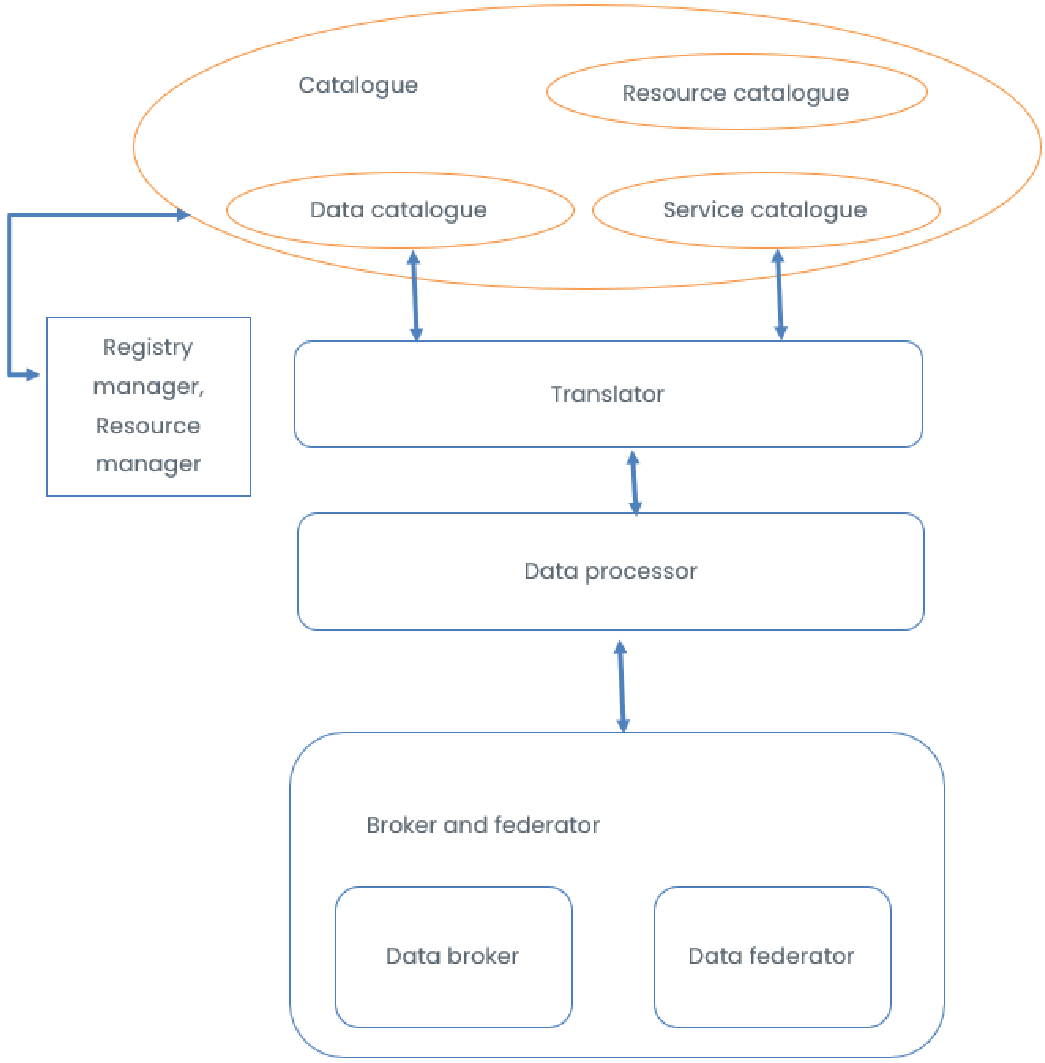


FIGURE 12: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE - DATA MANAGEMENT

Common capabilities:

- Data catalogue
  - Data catalogue (streams, APIs, DBs)
  - Service catalogue (for data exposure) - additional
- Data broker and federator
  - Data broker (routing)
  - Data federator - draw connectors blocks
    - Connectors (for multiple DBs)
    - Connectors (for multiple data spaces) - challenge: scalability issues (related to data lakes)

Funded by Horizon Europe Framework Programme of the European Union

- Translator (lowest level to connect DBs) - ensuring interoperability and connected with DR&F, uses data catalogue for information on data models
- Data processor(also providing information for scheduling)
    - Batch processor
    - Stream processor

Optional (not mandatory) / Additional components:

- Backup/Replicas' automated manager (using metadata from data catalogue)

For scheduling data:

- Orchestrating data for analytics

Future research challenges:

- Data lakehouse implementation

Resource management

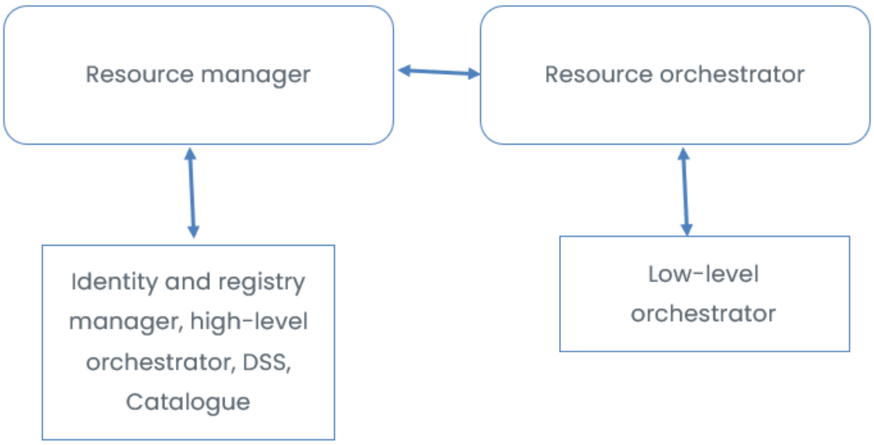


FIGURE 13: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE - RESOURCE MANAGEMENT

Definition of resource management:

Resource management in cloud, edge, and IoT is the process of efficiently allocating, balancing, provisioning, and scheduling the resources (such as heterogeneous computing power, storage, network bandwidth, etc.) among the different layers of the system to achieve optimal performance, quality of service, energy efficiency, and cost reduction. Resource management techniques can vary depending on the specific characteristics and requirements of each layer and the applications running on them.

Funded by Horizon Europe Framework Programme of the European Union

Challenges and objectives of resource management in cloud, edge, and IoT are:

- Scalability: The system should be able to handle the increasing number of devices, data, and requests without compromising the quality of service.
- Heterogeneity: The system should be able to deal with the diversity of devices, resources, platforms, and protocols in the cloud, edge, and IoT layers.
- Latency: The system should be able to minimize the delay between the data generation and processing, especially for time-sensitive applications.
- Reliability: The system should be able to ensure the availability and fault-tolerance of the resources and services in the presence of failures and uncertainties.
- Security: The system should be able to protect the data and resources from unauthorized access and malicious attacks.
- Privacy: The system should be able to preserve the confidentiality and anonymity of the data and users in the cloud, edge, and IoT layers.

Some of the existing resource management techniques for cloud, edge, and IoT are:

- Resource allocation: The process of assigning resources to tasks or applications based on their requirements and preferences. Resource allocation can be done statically or dynamically, centrally or distributedly, deterministically or probabilistically, etc.
- Resource provisioning: The process of adjusting the amount and type of resources according to the changing demand and supply. Resource provisioning can be done proactively or reactively, based on historical data or real-time feedback, etc.
- Task scheduling: The process of determining the order and timing of executing tasks on resources to optimize certain objectives, such as completion time, energy consumption, cost, etc. Task scheduling can be done online or offline, based on priority or deadline, etc.
- Workload balance: The process of distributing the workload among the available resources to avoid overloading or underutilization. Workload balance can be achieved by using load balancing algorithms, such as round-robin, least connections, weighted round-robin, etc.

Blockdiagram

Simplified from feedback gathered about minimum functionalities:

Funded by Horizon Europe Framework Programme of the European Union

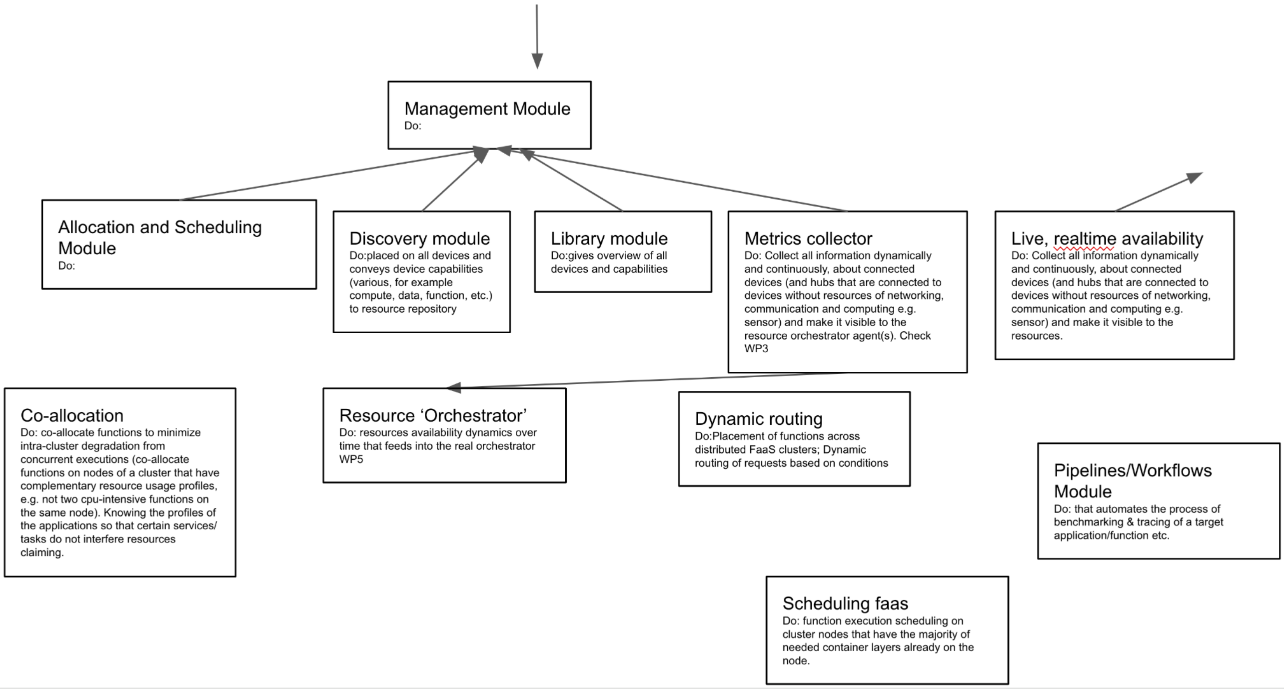


FIGURE 14: BLOCKDIAGRAM OF MINIMUM FUNCTIONALITIES

- Management and scheduling module: managing all computational resources, including IoT devices.
- Allocation module: assigning resources for application execution.
- Discovery module: selecting the most suitable resource for any specific action.

Funded by Horizon Europe Framework Programme of the European Union

Orchestration

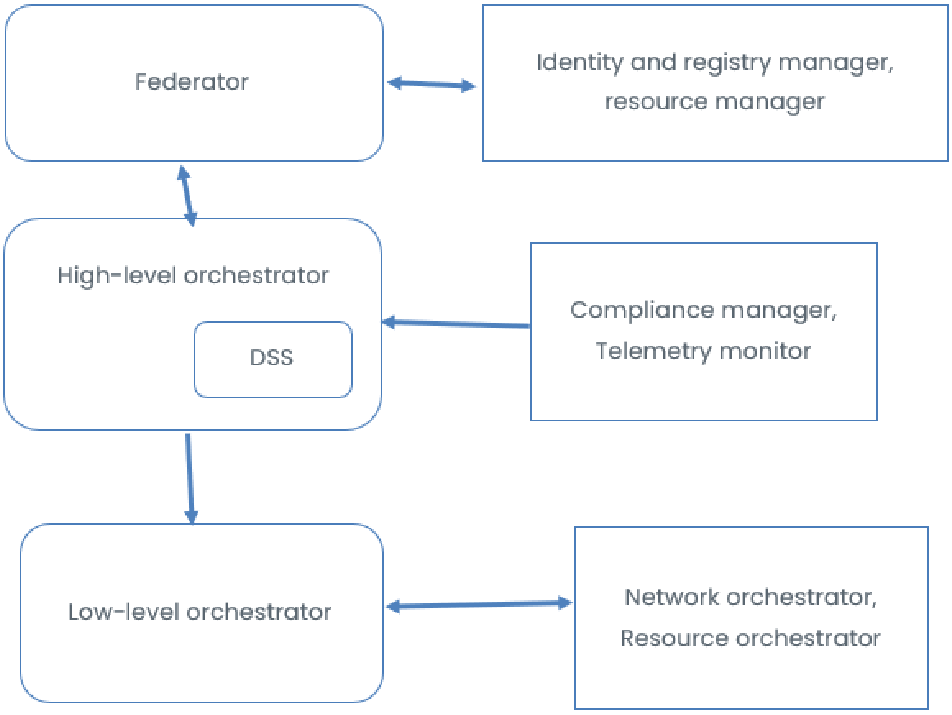


FIGURE 15: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE - ORCHESTRATION

Common capabilities

- Federation
  - Resource registry – as part of the work done within building block 1 (Security & Privacy)
  - Resource management – as part of the work done within building block 4 (Resource management)
  - Federator: taking care of the enablement of the most suitable spot for a specific deployment (linked with DSS developed within building block 8 – Artificial Intelligence). Shares information with the high-level orchestrator
- Service description
  - Decomposer: stores service description (linked with building block 3 – Data management for data storage/management). Information to be shared with DSS (building block 8 – Artificial Intelligence).
  - Both storage and the format on how the services must be described.
- High-Level Orchestration:
  - Security guarantees must be undertaken - links with building block 1 – Security & Privacy. Also, security related to resources should be considered.

Funded by Horizon Europe Framework Programme of the European Union

  - Data resources should also be addressed.
  - Meta-orchestrator: in charge of orchestrating and re-orchestrating (in case any event occurs – info coming directly from monitoring system (building block 7 – Monitoring & Observability) if it's something immediate or from the DSS (building block 8 – Artificial Intelligence) if the priority is lower). Sends this information to the low-level orchestrator which manages the deployment (building block 6 - Network). Shares information with the federator in case there's the need of managing infra/resources for establishing a new cluster.
- Low-Level Orchestration:
  - Include a composability necessary element called **"ADAPTER(s)"** that will make use of different interfaces to solve the complexity of underlying (needed connections). Example: edge node with very specific API to manage/handle.
  - Orchestrator: manages (and triggers) the deployment of an application, including autoscaling. Building block 6 (Network) enters into force if there is a requirement of initiating resources (such as NFV network slicing).

Specific for UCs

- FaaS Scheduling: Workflows of stateful functions (actors) generate asynchronous function calls as events which are routed within the same orchestration domain, or other orchestration domains, through a data plane where scheduling across multiple instances is based on weights/priorities.

Network

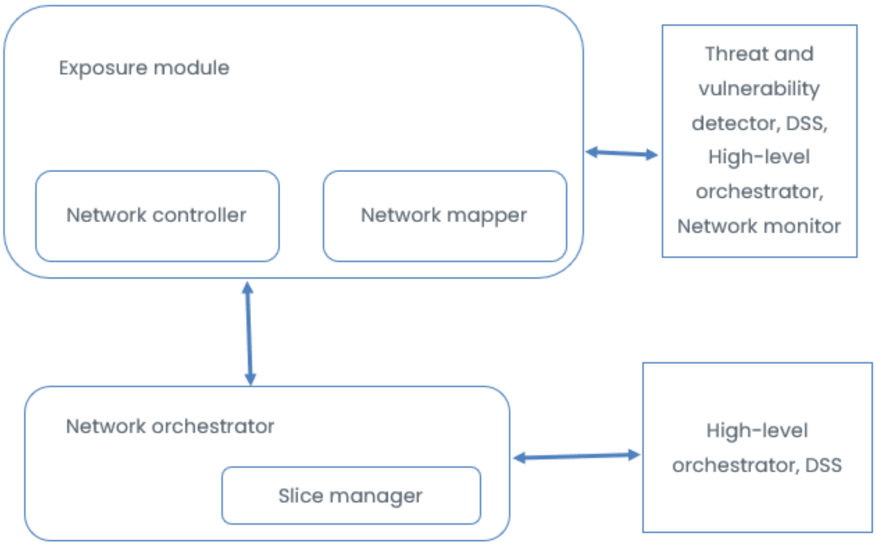


FIGURE 16: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE - NETWORK

Common capabilities:

- Exposure module: for network topology (to share information with the DSS for developing the deployment pattern)
    - Network controller: direct network topology data model
    - Alto protocol (network map): aggregator on top of the network controller
- Network orchestrator: orchestrate network resources (related to building block 5 – Orchestration)
    - Slice manager: provide slices under request to deploy applications.

Additional considerations of the Exposure module:

- Network management: manage network connectivity across all system components; receive monitoring data (coming from building block 7 – Monitoring & Observability) or security threats (from building block 1 – Security & Privacy) to perform corrective actions.
- Monitoring network data (from building block 7 – Monitoring & Observability): considered metrics: latency within the node, flow identification, CPU usage, battery charge, position of the node, RSSI of wireless links, network performance parameters (load and end-to-end latency), flow-level statistics
    - including in-network telemetry module: computing flow-level statistics directly in the data plane of network switches
- Network function acceleration: accelerating network functions (NAT, LB, Firewall, packet authentication, etc.) in host stacks (e.g., with eBPF), smartNICs and DPUs, and network switches

Optional (not mandatory) / Additional components:

- Intelligent control plane (related to building block 8 – Artificial Intelligence): AI/ML for anomaly detection, network security (building block 1 – Security & Privacy), resource management
    - including swarm intelligence: leveraging switches and smartNICs for automating swarm operation with little interaction from control nodes: identification of nodes, swarm formation, isolation of traffic of different swarms

Monitoring & Observability

Funded by Horizon Europe Framework Programme of the European Union

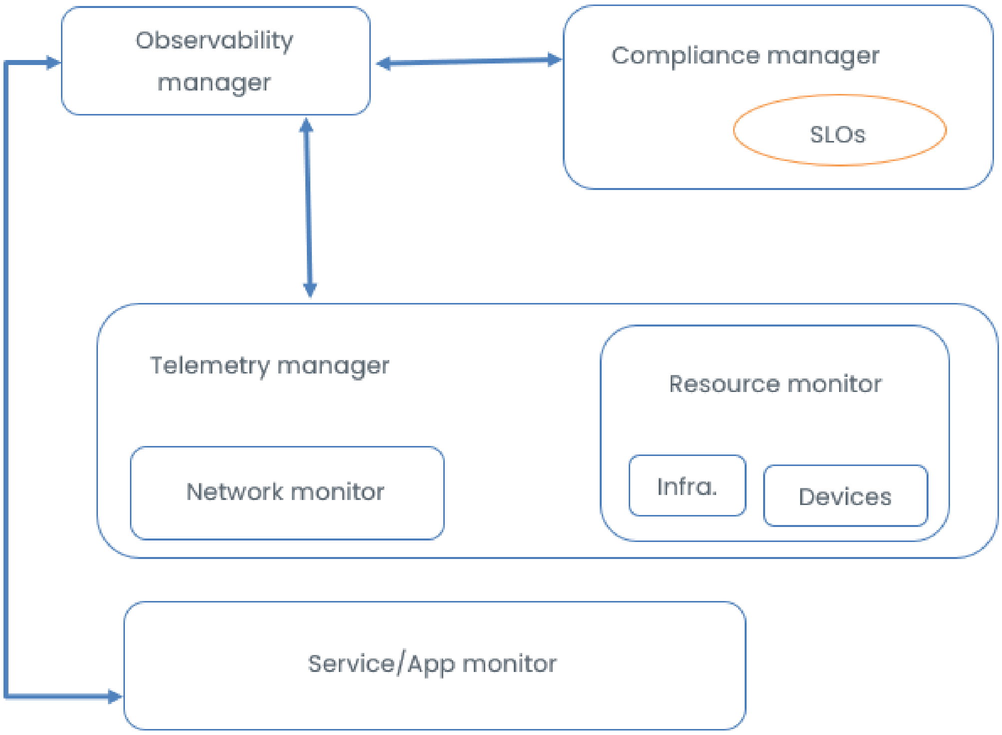


FIGURE 17: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE - MONITORING AND OBSERVABILITY

Common capabilities:

- Application monitoring module: monitoring the status of the application to identify underperformance issues not related to network or physical devices.
- Telemetry monitoring module: monitoring the connectivity status of the system to identify information loss.
- Infra monitoring module: monitoring the status of the infrastructure (mainly related to computing boxes or servers, those physical devices with high processing capabilities).
- Resource monitoring module(s): monitoring physical devices (mainly IoT ones).
- QoS/QoE module: containing metrics thresholds, established by default or further negotiated with the user and/or provider.
- Smart Observability module: gathering feedback from the monitoring modules and comparing it with the information stored in the QoS/QoE module to identify and predict breaches that must be prevented according to a previous negotiation.

The previously identified components provide the minimum set of functionalities to act/react according to the system and application health based on the specified params.

In case negotiation is out of the functionalities of this building block, it must receive these inputs from the building block in charge of it.

Major outputs rely on notifications about potential QoS/QoE breaches during the execution of an application or system malfunctioning (e.g., low device battery) as a recommendation for a better deployment pattern.

Funded by Horizon Europe Framework Programme of the European Union

Artificial Intelligence

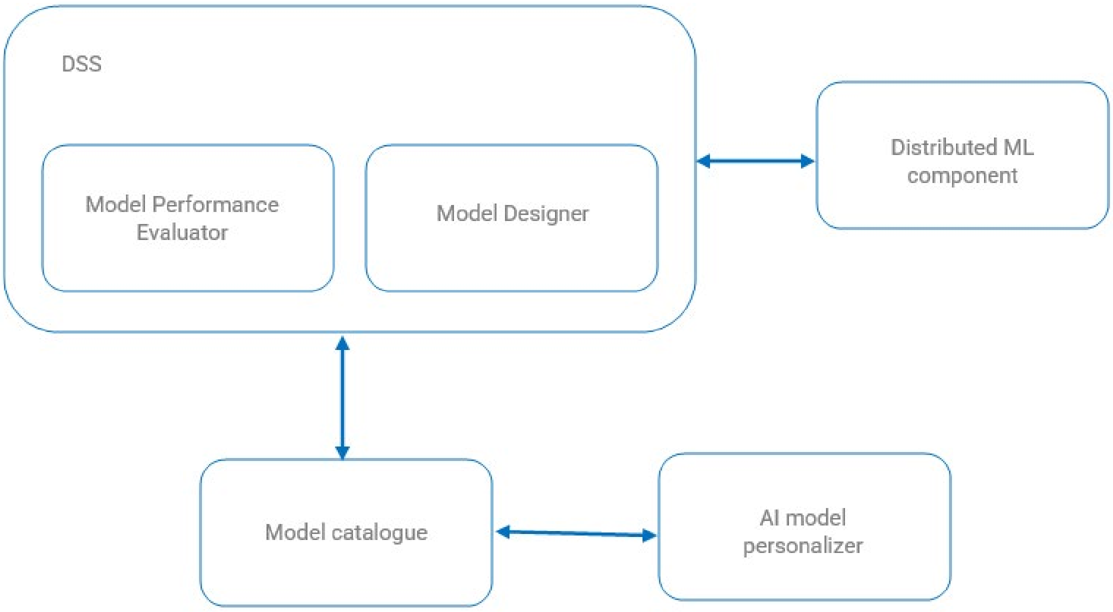


FIGURE 18: COMPOSITIONAL VIEW OF THE REFERENCE ARCHITECTURE - ARTIFICIAL INTELLIGENCE

Common capabilities:

- Decision Support System: providing recommendations for deployment patterns and resource orchestration (ad-hoc spots) + AI orchestration recommendations. It also includes mapping functionalities
  - Model performance evaluator + optimizations: to readapt the pattern to changeable conditions
  - Model designer: to develop the most suitable pattern adapted to each specific case
  - Model catalogue: model instances storage

. **Optional (not mandatory) / Additional components:**

- Distributed ML component: for managing the lifecycle of AI/ML models in distribute environments
- AI model personalizer: allowing users to adapt existing models to their specific needs, including combining 2 or more, without the need to develop a new model

Funded by Horizon Europe Framework Programme of the European Union

4 CONCEPTUAL FRAMEWORK AND LANDSCAPE

This section reminds the methodology followed to analyse the results of the research projects, already presented in D2.1, as well as the analysis itself to identify gaps, as well as strengths and weaknesses in the current research arena.

4.1 METHODOLOGY

Based on the IMAF methodology [1], OpenContinuum has developed its own methodology to evaluate the quality of the results in order to provide recommendations to maximise their impact and to identify some gaps where additional support from funding bodies is needed.

According to this methodology, there are several factors to be taken into account:

Functional Capability

This section measures the reusability and replicability of the asset in a given context. It is of paramount importance to determine if any results can be used out of the project and, even more, after the end of the project. Thus, first step is to determine the quality, and quantity, of the information provided to external stakeholders to support decision makers in their evaluation processes.

Technological Capability

Another important aspect to be considered is the maturity of results, so any potential adopter can determine the investment needed to reuse any of the identified results. Furthermore, it is also of paramount importance to determine the dependencies the software may have to identify the adaptability potential of the solution.

Operational Capability

This part of the questionnaire evaluates the long-term sustainability of the results once the project has ended. This is, indeed, a crucial factor taken into account by any potential adopter prior to take any decision about investing, or not, in any of these results.

Engagement Capability

Finally, there is some previous work to be done before the end of the project to disseminate results while foster their adoption. In this sense, this section analyses the work done and the reasons why it was not possible to reach, or engage, external stakeholders as well as the plans to do so after the end of the project.

The whole methodology, as well as the scoring mechanisms, is published on the project website.

Funded by Horizon Europe Framework Programme of the European Union

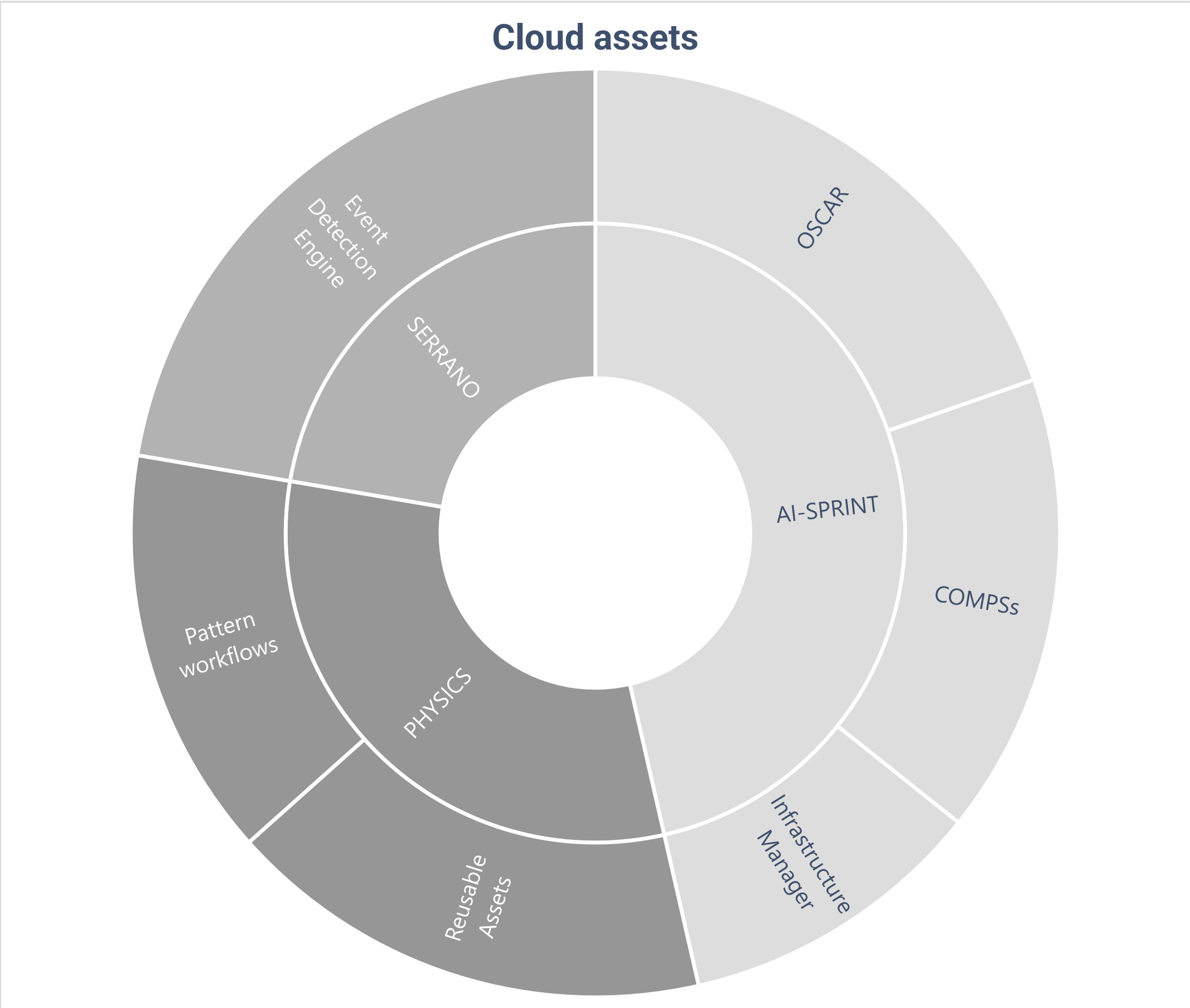
4.2 RESULTS

During the last year of the project, the survey was opened in order to allow the participation of all projects involved in TF3. 77 results were collected and analysed from 17 different projects. The results of the overall analysis are as follows:

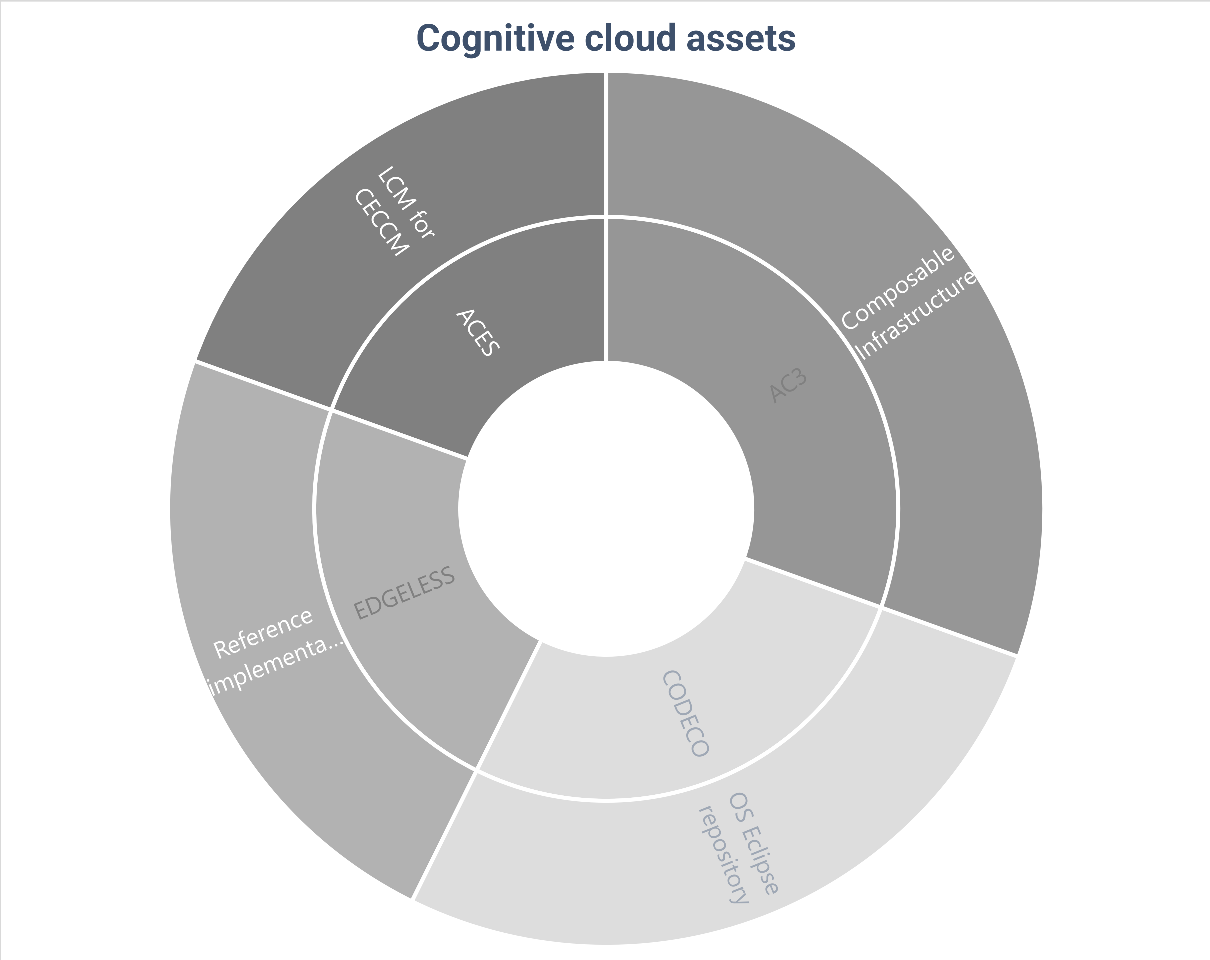
Basic Information

All projects were requested to provide public information about their assets, including a basic description, links to source code and documentation, demos and tutorials as well as the contact to whom external stakeholders will be redirected in case they are interested in any of the assets.

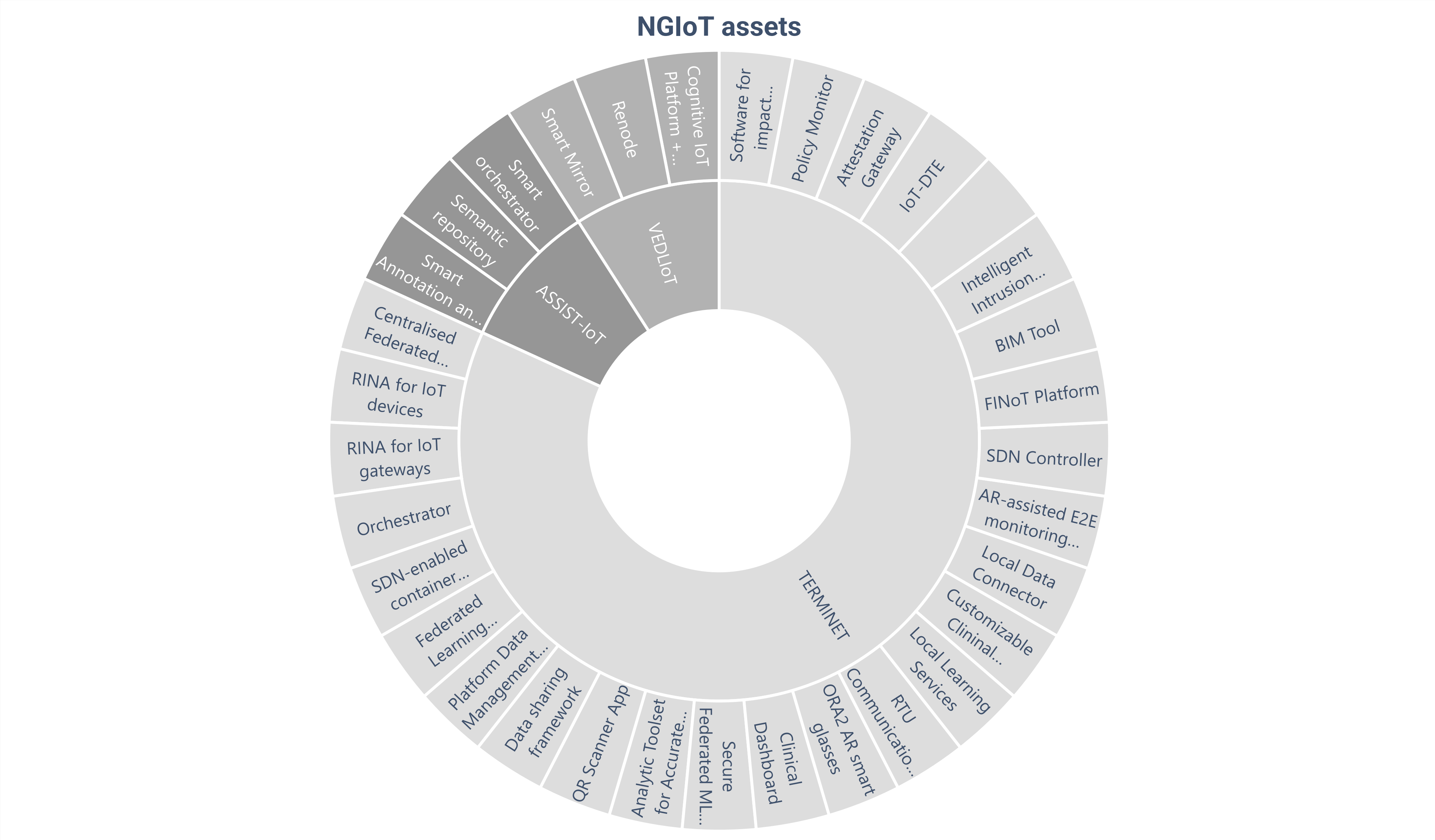
The following diagrams show the collected assets per project and call.



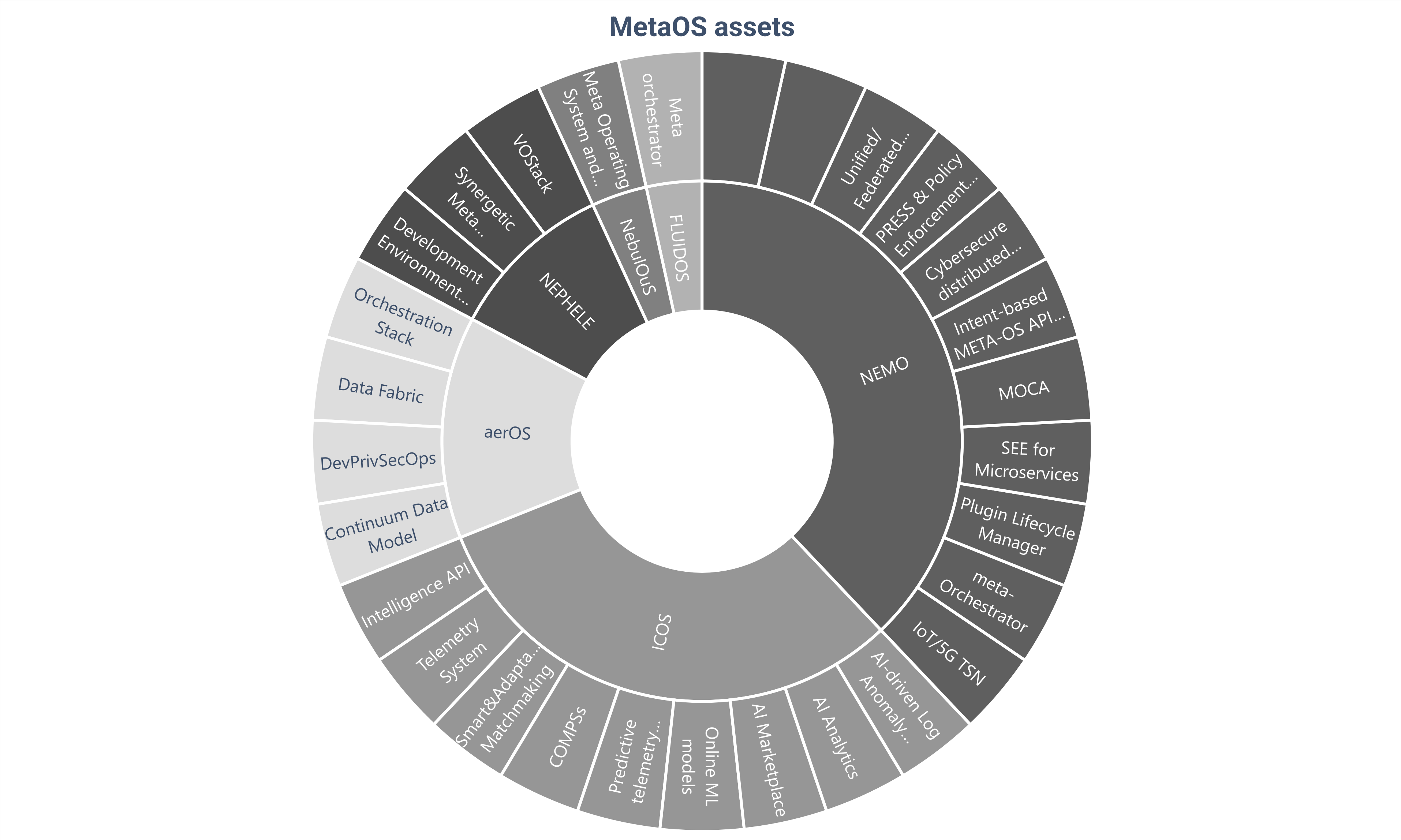
Funded by Horizon Europe Framework Programme of the European Union

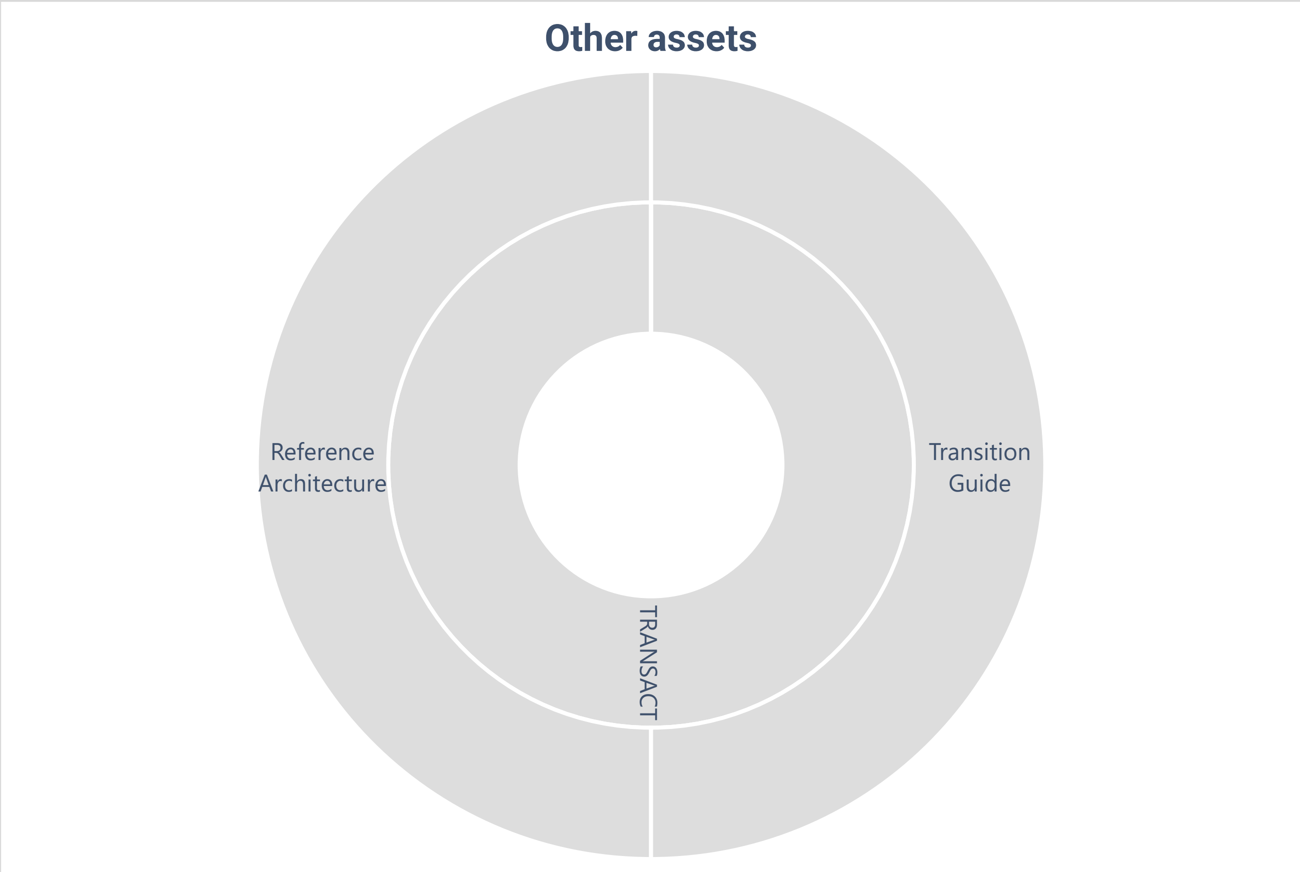


Funded by Horizon Europe Framework Programme of the European Union



Funded by Horizon Europe Framework Programme of the European Union


MetaOS assets
NEMO
ICOS
aerOS
NEPHELE
NebulOuS
FLUIDOS
Meta orchestrator
Meta Operating System and...
VOStack
Synergetic Meta...
Development Environment...
Orchestration Stack
Data Fabric
DevPrivSecOps
Continuum Data Model
Intelligence API
Telemetry System
Smart&Adapta... Matchmaking
COMPSs
Predictive telemetry...
Online ML models
AI Marketplace
AI Analytics
AI-driven Log Anomaly...
IoT/5G TSN
meta-Orchestrator
Plugin Lifecycle Manager
SEE for Microservices
MOCA
Intent-based META-OS API...
Cybersecure distributed...
PRESS & Policy Enforcement...
Unified/ Federated...



All this information is available within the project landscape.

It is important to highlight that not all projects were able to contribute with assets, or to provide detailed information, due to their different lifespans. This is also reflected in the different TRLs as showed in the following figure:

Funded by Horizon Europe Framework Programme of the European Union

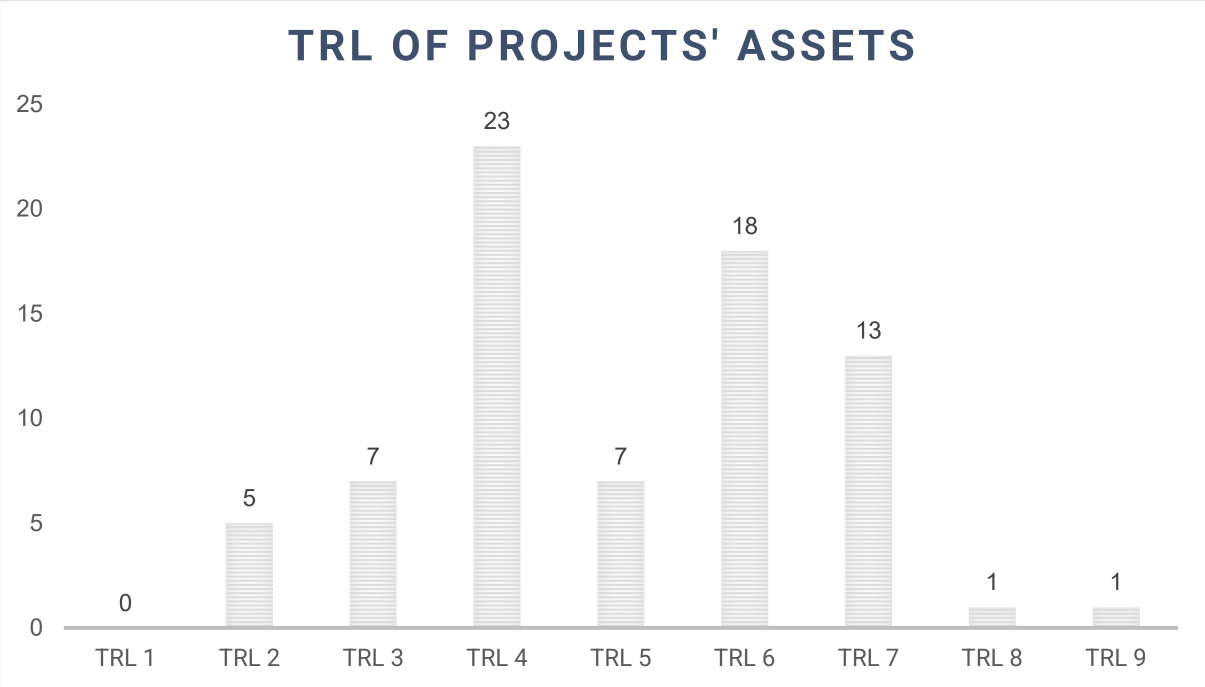


FIGURE 19: TRL OF PROJECTS' ASSETS

Finally, an overview of the domains where the results were tested was also requested:

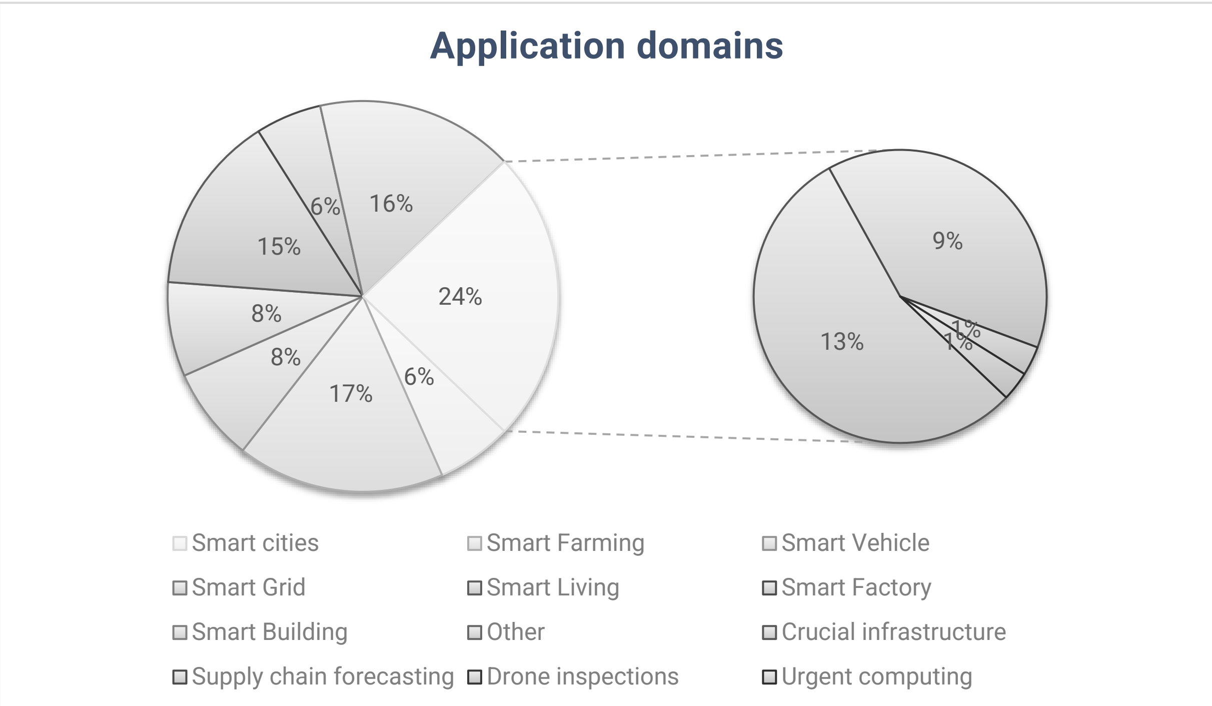


FIGURE 20: APPLICATION OF DOMAINS

Functional Capability

The analysis of this capability goes one step further the considerations of the previous one, as it takes into account all information needed by external stakeholders for taking the decision whether to use a piece of software or not.

There are three main aspects to be taken into account:

i) Is the software available? This includes not only the source code, but all the needed documentation as well as interoperability issues, such as standardised procedures or even the applied license.

ii) Is there any support? Offering support is almost mandatory, as whenever someone decides to use a piece of software, many questions may arise when using it.

iii) Is there any information about how costly is to use it? Finally, costs are a crucial point for taking a decision. Thus, any documentation about how many efforts should be invested or how to replicate a given scenarios will tip the scale.

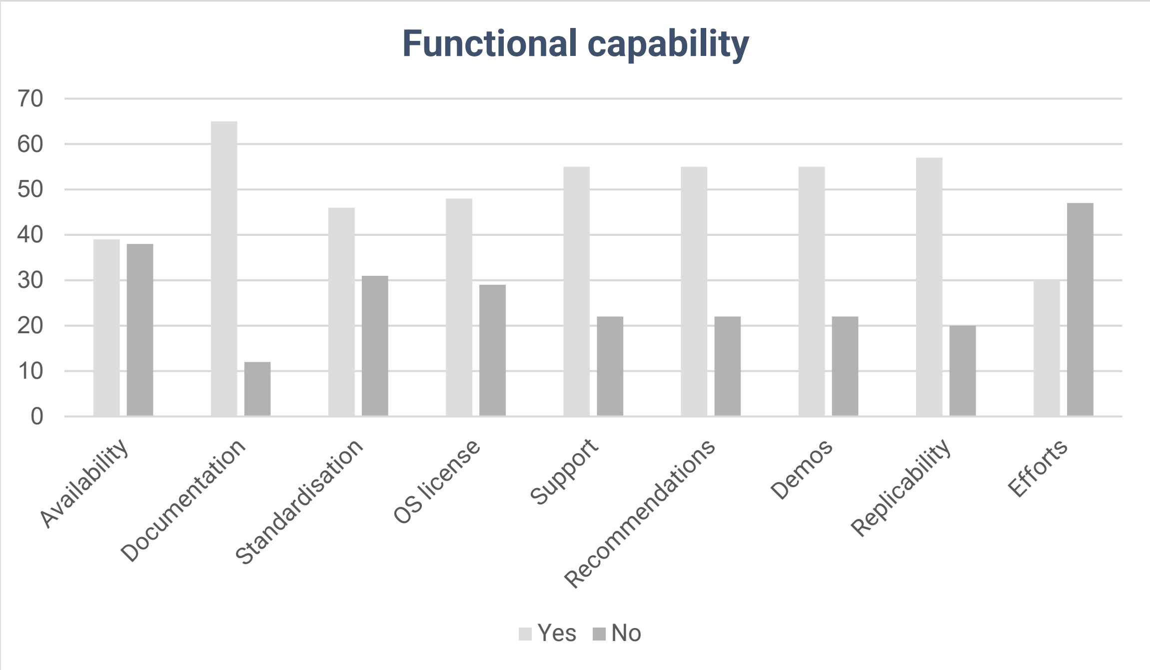


FIGURE 21: FUNCTIONAL CAPABILITY

As it can be seen in the figure above, most of the projects have available source code, however, the lack of documentation or support offered to third parties is harming the potential adoption of their results. Additionally, a replicability plan, including an estimation of the efforts needed to use or adapt the software, as well as a set of recommendations about how to do so should be considered as a must have for future projects.

Technological Capability

Another capability to be taken into account, is the technological one. This specifically measures the investment needed to adopt a solution taking into account aspects such as the use of additional technology from third parties or additional investments to have a fully operational prototype.

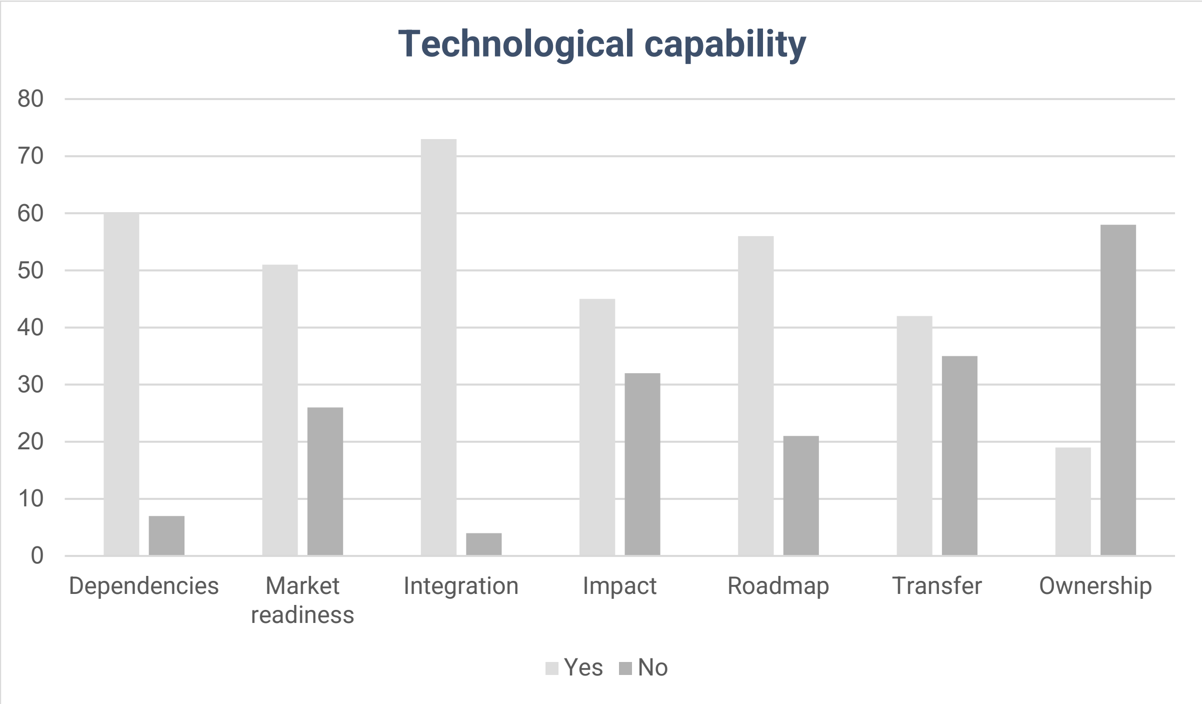


FIGURE 22: TECHNOOGICAL CAPABILITY

Having a look to the information provided by the project and combining it with the answers to the previous questions, there is a clear gap within the information provided, as the results have clear dependencies with third party software but there is not enough documentation available. This can be clearly a painful adoption point.

Another weak point is the existence of joint ownership when there is not a clear roadmap for the solution after the end of the project.

Operational Capability

Measuring the operational capabilities of the organisations providing the software is important to determine the sustainability of the results at the end of the project. In this sense, projects were requested to provide information about the minimum needed to ensure sustainable results.

Funded by Horizon Europe Framework Programme of the European Union

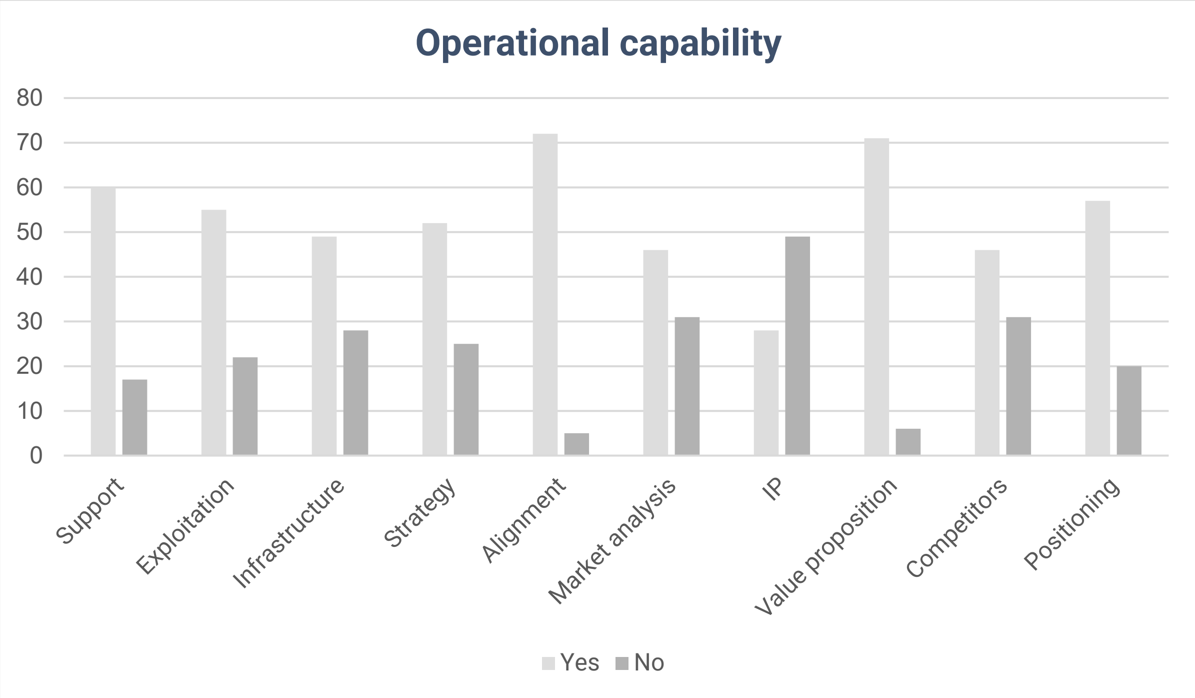


FIGURE 23: OPERATIONAL CAPABILITY

Opposite to the previous ones, this is something internal as all organisation offering results to external stakeholders must be able to define what they will offer, to whom and how. Even if there is a majority of them who already make the preliminary studies needed to develop an exploitable asset, there are still many other that need further work before the end of the project. As many of the answers belong to ongoing projects, this is something that can be solved during the project lifespan. However, it is important to take into account that this is almost a mandatory prerequisite to ensure the sustainability of the identified results.

Engagement Capability

Finally, this capability measures the work done by all projects to reach potential end users in order to determine if some extra work is needed or if further support from the funding bodies must be provided.

Funded by Horizon Europe Framework Programme of the European Union

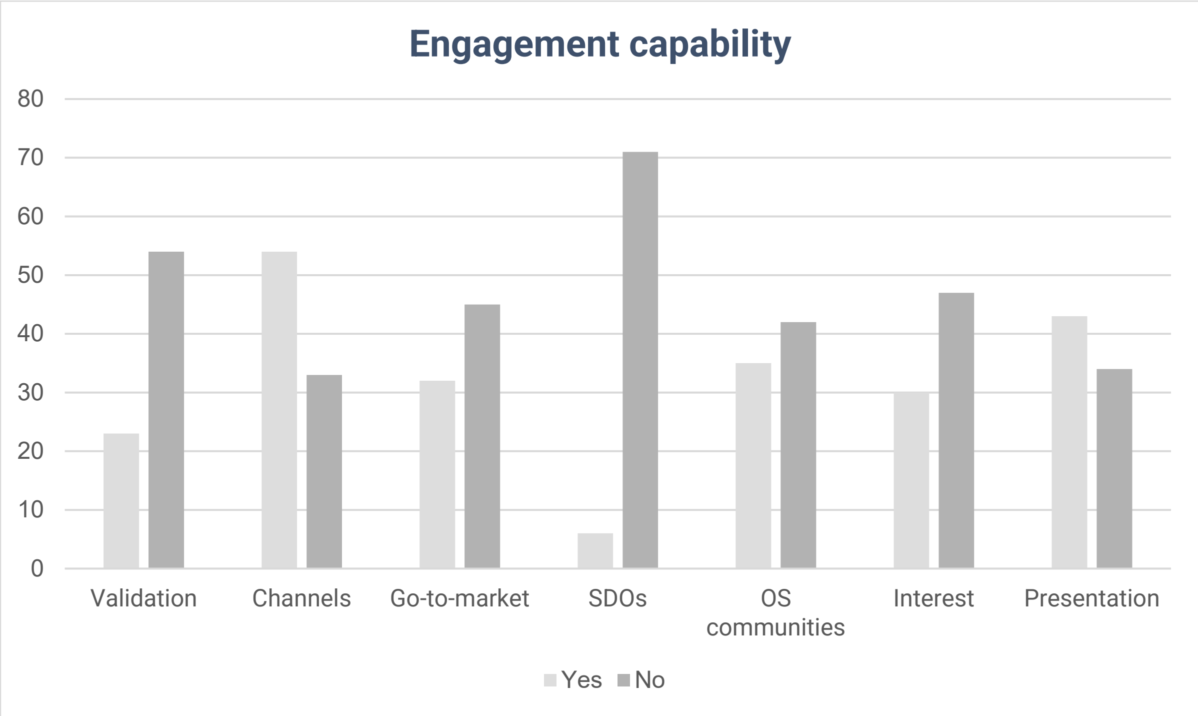


FIGURE 24: ENGAGEMENT CAPABILITY

The result of this analysis is aligned with the results of the previous one, as even if projects have a clear value proposition for their assets, there is still much work to do in order to position themselves before reaching the appropriate stakeholders. From a commercialization point of view only, reaching someone interested in paying for a piece of software is a one-shot action, as if there is not a clear underlying plan there will not be further interest.

Thus, even if technically the results are of high quality, there is a clear weakness in the proper exploitation of them that must be solved to allow projects reach their maximum potential.

The information about all these results can be seen in the online actionable landscape as shown in the following figure.

Funded by Horizon Europe Framework Programme of the European Union

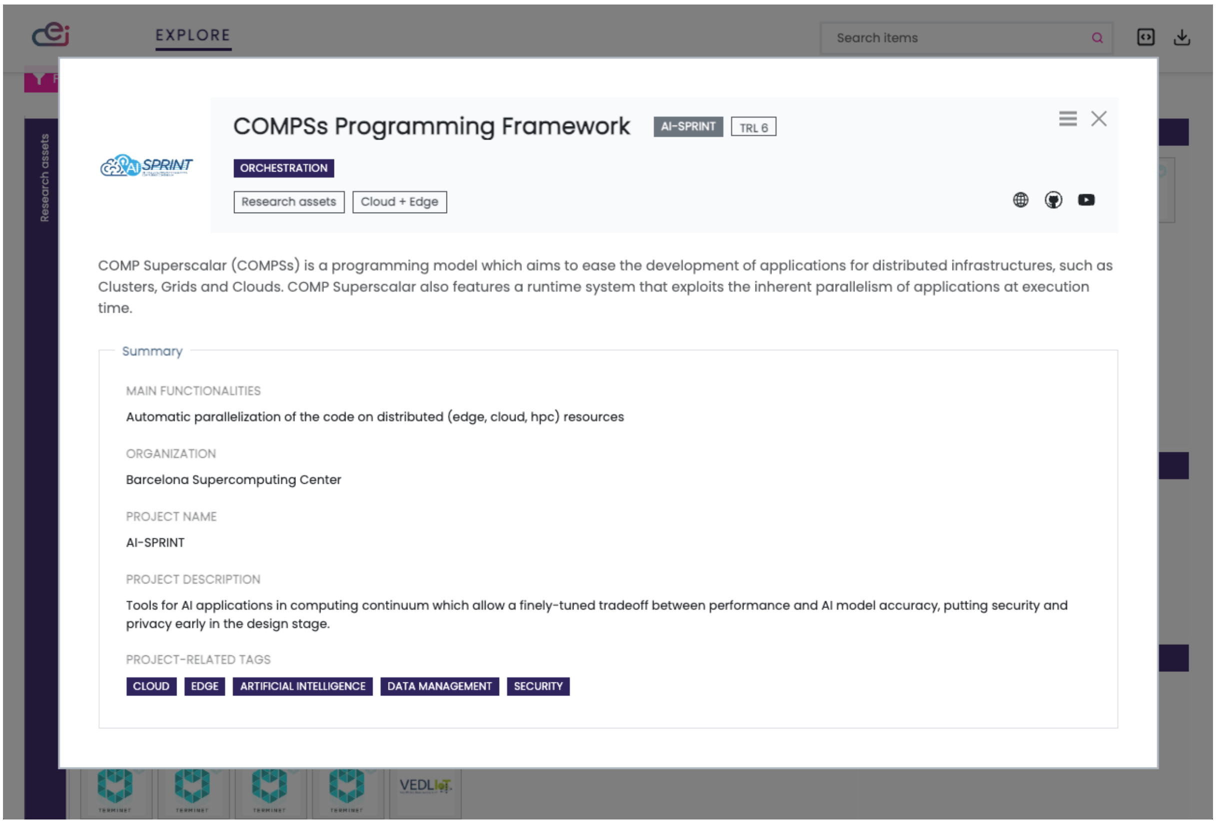


FIGURE 25: ROADMAP

Additional to this analysis, a roadmap has been published including some research gaps identified by ongoing research projects. The roadmap contains some challenges that may be considered for future work programmes.

A summary of them can be seen in Annex 5.

Funded by Horizon Europe Framework Programme of the European Union

5 RECOMMENDATIONS FOR THE FUTURE WORK

Based on the results of the work performed, there is a set of recommendations to be taken into account:

- Many projects are addressing different aspects of the continuum from different perspectives. However, there are clear relationships among them in terms of, e.g., most commonly used technology. Foster collaboration between them should be something mandatory, as it can enrich their results and support the development of more mature technology. However, it is important to do this even at proposal phase, as during the project lifespan developments may vary causing incompatibilities between them. Additionally, something that can be considered is to give priority to proposals that are addressing different challenges, as it will avoid overlapping of results.
- Most of the projects develop results with a low TRL what, in principle, it is not inconvenient. However, there are still some gaps in terms of sustainability at the end of the project, e.g., with further support or contributions to an established community. In this sense, the support from CSAs has demonstrated to be of paramount importance as they connect project participants with external stakeholders, such as industry representatives, standardisation bodies or open source communities. Thus, further initiatives must be taken into account while providing more than communication support.
- Following with the previous recommendation, exploitation is still weak and not only in terms of monetization. For example, not many projects reuse results from previous ones. Thus, there is a technology loss in terms of reusability. Further investments must be done in this sense, as there is pretty much cutting-edge technology developed in the context of research that can set the basis for future research activities increasing the European positioning.
- There is a lack of harmonisation in the continuum itself, as there are plenty of different architectures that present incompatibilities among themselves. In this sense, the definition of a reference architecture is a preliminary step. However, the usage of it must be fostered.

WP2 and TF3 have focus their work in homogenising the continuum view, while giving visibility to projects results and looking for synergies between their architectures. Now, even if the project has ended, the work will continue as there is a preliminary work item ongoing within ISO to standardise the taxonomy and the patterns already identified. This, definitely, will support the European positioning in the worldwide research arena.

Funded by Horizon Europe Framework Programme of the European Union

REFERENCES

[1] "Taxonomy Best Practice Framework," [Online]. Available: https://www.ons.gov.uk/methodology/classificationsandstandards/taxonomybestpracticeframework.

[2] "NIST taxonomy for cloud," [Online]. Available: https://www.nist.gov/publications/nist-cloud-computing-reference-architecture.

[3] «LF glossary for edge,» [En línea]. Available: https://github.com/State-of-the-Edge/glossary/blob/master/PDFs/OpenGlossaryofEdgeComputing_2019_v2.0.pdf.

[4] TF3, «Functional view of the reference architecture,» [En línea]. Available: https://zenodo.org/records/11656674.

[5] TF3, «Compositional view of the reference architecture,» [En línea]. Available: https://zenodo.org/records/11656784.

[6] "ICCC Maturity Assessment Framework," [Online]. Available: https://iccc.smartcities.gov.in/assets/frontend/extra-images/IMAF-ICCC-Maturity-Assessment-Framework.pdf.

Funded by Horizon Europe
Framework Programme of the European Union

ANNEX 1: RESEARCH ASSETS

During the project lifespan, a survey was shared with the projects involved in TF3. All projects provided the assets considered as mature enough to be easily reused by external stakeholders, as well as all the information needed to assess them about how to improve the impact they may have and find gaps where more support is needed to maximise it.

The tables below contain the public information provided by them, that is also available through the actionable map (aka online landscape), while the confidential one is only analysed in Section 7.

The structure of the information is as follows:

- *Name of the asset:* to easily identify the asset.
- *Short description:* of the functionalities provided justifying for what the asset is useful for.
- *TRL and MRL:* to provide additional information to decision makers about how big the investment will be if they decide to use the asset.
- *License:* to identify how many results are produced as open source and how many as commercial products.
- *Owner:* to let external stakeholders know who to contact in case they are interested in the asset.
- *Domain(s) where tested:* to highlight the achieve results in different application domains.
- *OC tag level 2 and 3:* to map results with the reference architecture in order to identify gaps and challenges.

Funded by Horizon Europe
Framework Programme of the European Union

AI SPRINT

Tools for AI applications in computing continuum which allow a finely-tuned tradeoff between performance and AI model accuracy, putting security and privacy early in the design stage.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
COMPSs Programming Framework	COMP Superscalar (COMPSs) is a programming model which aims to ease the development of applications for distributed infrastructures, such as Clusters, Grids and Clouds. COMP Superscalar also features a runtime system that exploits the inherent parallelism of applications at execution time.	6	Apache 2	Barcelona Supercomputing Center	Smart City; healthcare; Smart Vehicle; Smart Farming;	Edge, Cloud	**Orchestration**
OSCAR	OSCAR is an open-source platform to support the event-driven serverless computing model for data-processing applications. It can be automatically deployed on multi-Clouds, and even on low-	TRL 7	Apache 2.0	Universitat Politècnica de València (UPV)	Smart Farming; Smart Living;	Edge, Cloud	**Data Management**, **Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

	powered devices, to create highly-parallel event-driven data-processing serverless applications along the edge-to-cloud continuum. These applications execute on customized runtime environments provided by Docker containers that run on elastic Kubernetes clusters.						
Infrastructure Manager (IM)	IM is an open-source TOSCA-based runtime orchestrator for the cloud-to-edge continuum. It deploys complex and customized virtual infrastructures on IaaS Cloud deployments (such as AWS, OpenStack, etc.). It eases the access and the usability of IaaS clouds by automating the VMI (Virtual Machine Image) selection, deployment, configuration, software installation, monitoring and update of the virtual infrastructure. It supports APIs from a large number of virtual	TRL 8	GPL 3.0	Universitat Politècnica de València (UPV)	Smart Living; Smart Farming;	Edge, Cloud	**Orchestration**

	platforms, making user applications cloud-agnostic. In addition, it integrates a contextualization system to enable the installation and configuration of all the user required applications providing the user with a fully functional infrastructure. It can also interact with serverless platforms such as OSCAR to support the deployment of complex applications along the computing continuum.						

Funded by Horizon Europe
Framework Programme of the European Union

ASSIST-IOT

Reference architecture in which intelligence can be distributed among nodes by implementing artificial intelligence and machine learning close to data generation and actuation, and hyper connecting nodes, in the edge-cloud continuum, over softwarised smart networks.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Smart orchestrator	The Smart Orchestrator simplifies how user interfaces and other services interact with the primary components of the MANO framework and Kubernetes (K8s) clusters. This enabler manages the complete lifecycle of containerized applications and services, from the cluster selection, instantiation, policy-based connectivity with other services and termination.	TRL 6, MRL N/A	Apache 2	Polytechnic University of Valencia	Smart Vehicle;	Cloud	**Data Management, Orchestration**
Semantic Repository	File storage system with metadata and documentation management capabilities. Facilitates storing and exchanging data models and other files.	TRL 7	Apache 2.0	Systems Research Institute, Polish Academy of Sciences	Smart Vehicle; Construction industry (health & safety);	Cloud	**Data Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Semantic Annotation and Translation enablers	Two components for realizing semantic interoperability in streaming systems. Semantic annotation adds semantics to non-semantic data, and translation facilitates interoperability between different ontologies.	TRL 7	Apache 2.0	Systems Research Institute, Polish Academy of Sciences	Smart Factory;	Cloud	**Data Management**

Funded by Horizon Europe Framework Programme of the European Union

EDGELESS

Orchestration system that provides a flexible horizontally scalable compute solution able to fully use heterogeneous edge resources, while preserving vertical integration with the cloud and the benefits of serverless.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
EDGELESS reference implementation	A reference implementation of the controller (ε-CON), orchestrator (ε-ORC), and balancer (ε-BAL) components of the EDGELESS architecture, along with a run-time environment based on WebAssambly for stateful FaaS on resource-constrained edge nodes.	TRL 3	MIT	Respective source code contributors	Not yet tested in a specific domain;	Edge	**Resource Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

SERRANO

Novel ecosystem of cloud-based technologies, ranging from specialised hardware resources to software tool sets.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Event Detection Engine	The event detection engine is a distributed framework designed for consuming data/monitoring metrics from various sources and train ML based predictive models used for performance anomaly detection.	6	Apache 2.0	UVT/IeAT	Smart Grid; Smart Factory; HPC/IoT/Exascale performance monitoring;	?	**Data Management, Artificial Intelligence**
SERRANO Resource Orchestrator	The SERRANO Resource Orchestrator is a high-level orchestrator that enables end-to-end cognitive resource orchestration and transparent application deployment over edge, cloud, and HPC resources. It is designed to manage edge and cloud platforms that use Kubernetes (K8s) as their Local Orchestrator and HPC platforms based on Slurm and OpenPBS. The Resource Orchestrator	TRL 4	open-source	Institute of Communication and Computer Systems (ICCS) / National Technical University of Athens (NTUA)	Smart Factory; Fintech analysis;	Edge, Cloud	**Resource Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

	oversees the e2e operation of the unified platforms and interacts with the multiple Local Orchestrators that handle individual parts of the overall infrastructure.						

Funded by Horizon Europe Framework Programme of the European Union

HE-CODECO

Cognitive, cross-layer and highly adaptive Edge-Cloud management framework with a unique orchestration approach that provides support for data management and governance decentralised data workflow; dynamic offloading of computation and computation status; and adaptive networking services.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
CODECO Open-source Eclipse repository	The CODECO open-source Eclipse repository is a developer-oriented, open-source software repository. An early release of CODECO components is already available via https://gitlab.eclipse.org/eclipse-research-labs/codeco-project, thus allowing for early exploitation of initial results in CODECO, such as proofs-of-concept with decentralised AI/ML to provide infrastructure resource forecasting; context-aware meta-data aggregation to allow for an orchestration based on data-network-compute.	3-4	Apache 2.0	Multiple partners own different components	Smart City; Energy, Mobility;	Edge, Cloud	**Data Management**, **Orchestration**, **Network**

AC3

Funded by Horizon Europe Framework Programme of the European Union

Agile and cognitive cloud-edge continuum management framework providing scalability, agility, effectiveness, and dynamicity in service delivery over the cloud edge computing continuum infrastructure.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
AI-based Life Cycle Management (LCM) for Cloud Edge Computing Continuum Management (CECCM)	AI-Driven Lifecycle Management (LCM) encapsulates an advanced framework that integrates Artificial Intelligence (AI) and Machine Learning (ML) algorithms to oversee and regulate the entire lifecycle of applications. This comprehensive mechanism extends from initial deployment through ongoing monitoring, dynamically adapting to fluctuations in application demand or alterations in the underlying infrastructure environment. It meticulously orchestrates the placement and real-time management of microservices across the cloud-edge continuum. By doing so, it not only optimizes operational performance but also ensures strict adherence to	With initial functionality expected to reach TRL 5-6 by the end of the project.	Open-source, mostly Apache 2.0	AC3 Consortium	The project is ongoing and we have three use-cases (IoT and Data, Smart Monitoring system using UAV, Deciphering the universe: processing hundreds of TBs of astronomy data) where the asset will be tested;	Cloud, Edge	**Security**, **Data Management, Resource Management, Orchestration, Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

	predefined Service Level Agreements (SLAs). This strategic deployment of AI technologies not only enhances efficiency but also fortifies the resilience and scalability of cloud-native architectures.						

Funded by Horizon Europe Framework Programme of the European Union

ACES

Infused autopoiesis and cognition on different levels of cloud management to empower with AI different functionalities.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Composable Infrastructure	The ACES project is collaborating with researchers from Micron technology to build a testbed with composable edge-datacenter infrastructure. The ACES project will demonstrate the value of CPU memory pooling (CXL level1.1). In Future projects we expect to extend the testbed to level 2.0 and finally 3.0, fully composable hardware and switching. Using swarm technologies and other AI/ML in among others the orchestration of resource pools (CPU's, GPU's XPU's, memories, Storage).	TRL 3-5	to be determined TBD	HIRO-MicroDataCenters BV	Smart Grid;	Cloud, Edge	**Resource Management, Orchestration, Artificial Intelligence**

FLUIDOS

Fluid, dynamic, scalable and trustable computing continuum that spans across devices, unifies edge and cloud in an energy-aware fashion, and possibly extends beyond administrative boundaries.

Funded by Horizon Europe Framework Programme of the European Union

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Meta orchestrator	FLUIDOS meta-orchestrator for a geo-distributed continuum	2	Apache 2	IBM	None;	Cloud, Edge	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

PHYSICS

Cutting-edge, scalable and cost-effective cloud models operated across multiple hardware types, locations, edge computing nodes and multi-cloud resources.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Pattern workflows for Cloud/Edge	The collection contains a set of pattern subflows that aim to aid in various aspects of a Cloud/Edge application. They can assist in application development, workflow or execution management as well as usage of Node-RED as an orchestration mechanism. Many of the flows have been designed for usage in combination or within the open source Openwhisk FaaS platform, however they can also be used as standalone flows in a typical Node-RED server environment.	4	Apache v2	Harokopio University of Athens and other PHYSICS partners	Smart Farming; Smart Factory; ehealth;	Cloud, Edge	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

H2020 PHYSICS Reusable Assets	Collection of Assets developed by the project or provided by external contributors. Complete details and instructions of using those assets is available at the project's Marketplace (PHYSICS RAMP)	3-8	Different Licence per Asset	PHYSICS Consortium	Smart Farming; Smart Factory;	Cloud, Edge, IoT	**Data Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

ICOS

Meta operating system for a continuum, addressing challenges of devices volatility and heterogeneity, service execution and performance, trust, security and privacy, and costs reduction.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
ICOS Telemetry System - Telemetruum	The asset aims at being a flexible and complete solution for collecting, storing and processing telemetry and logging data in the Cloud-Edge-IoT Continuum. Telemetruum allows an adaptive and automated deployment of collection, storage and processing units along the continuum taking into consideration connectivity and computational power constraints while preserving a unified and complete view on the status and the performance of the entire continuum. The asset offers telemetry data collectors for multiple infrastructure and platforms and an advanced policy-based alerting system.	TRL 2-4	Apache 2.0	Engineering Ingegneria Informatica S.p.A. (ENG)	Cloud-Edge Continuum infrastructures;	Cloud, Edge, IoT	**Data Management, Monitoring, Observability,**

Funded by Horizon Europe Framework Programme of the European Union

Smart & Adaptable Matchmaking	Intelligent and runtime allocation of resources into jobs/tasks	TRL2, MRL2	Proprietary	UPC	On process;	Cloud, Edge, IoT??	**Resource Management**
COMPSs	COMP Superscalar (COMPSs) is a task-based programming model which aims to ease the development of applications for distributed infrastructures, such as large High-Performance clusters (HPC), clouds, container-managed clusters and hyper-distributed infrastructures. COMPSs provides a programming interface for the development of the applications and a runtime system that exploits the inherent parallelism of applications at execution time.	TRL 3-5; 2-4	Apache 2.0	Barcelona Supercomputing Center	Smart Building; Smart Vehicle; Smart City; Urgent Computing;	Cloud, Edge, IoT	**Resource Management**
Predictive telemetry metrics model training	The AI coordination API offers an endpoint for estimating the CPU consumption of the ICOS agents. This model can be repurposed to specific tasks and other telemetry metrics as a training functionality is provided as a separate endpoint.	TRL2-4	GNU GPL v3	CEADAR	Smart Grid; Smart Farming;	Cloud, Edge, IoT	**Resource Management, Monitoring, Observability, Artificial Intelligence**

Online machine learning models for ICOS Intelligence	This is a separate packet to be deployed and complement the list of AI models reachable in the ICOS intelligence layer. These models bring online machine learning capabilities to the Intelligence layer to learn on the fly and adapt to dynamic and non-stationary data streams received in the continuum.	TRL2-4	Proprietary	CeADAR	Smart Farming; Smart Grid;	Cloud	**Artificial Intelligence**
ICOS AI Marketplace	ICOS will create a marketplace of models and solutions developed using the intelligence layer. The aim of this is to create a community of projects using and building intelligent applications for ICOS.	TRL4-5	GNU GPL v3	CeADAR	Smart Farming; Smart Grid;	Cloud	**Artificial Intelligence**
AI-driven Log Anomaly detection	Using a powerful trust and incident management, adapted to new functionalities, and an AI engine with features enhancing self-learning and self-healing capabilities, LOMOS (log based anomaly detection) allows to create informative metrics/variables with significant discriminative power. It addresses the need for monitoring stack for the run-time conditions so	TRL: 5, MRL: 5	Propriety	XLAB	Smart Grid; Crucial infrastructure;	Cloud	**Security, Trust, Monitoring, Artificial Intelligence**

	that the self- learning and self-healing mechanisms can be fed. Our solution is a monitoring system capable of detecting security-related events and incidents in the deployed application's environment. It is (to the extent possible) deployable automatically and notifies users about security alerts.						
ICOS Intelligence API	The AI coordination module facilitates optimisation, predictive analytics, and applying machine learning models across the edge-cloud continuum. Model outputs target the implementation of policies for utilising, sharing, and updating models. This acts as an interface and provides coordination between the meta-kernel and user layers providing and requesting services.	TRL4	GNU GPL v3	CeADAR	OS Meta-kernel;	Edge, Cloud	**Artificial Intelligence**
ICOS AI Analytics - Intelligence continuum models	ICOS will integrate a set of techniques for optimizing and pruning ML models to be adapted to the characteristics of edge devices without losing accuracy.	TRL4-5	GNU GPL v3	CeADAR	Smart Grid; Smart Farming;	Edge, Cloud	**Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

NEBULOUS

Meta Operating System and platform for enabling transient fog brokerage ecosystems that seamlessly exploit edge and fog nodes, in conjunction with multi-cloud resources, to cope with the requirements posed by low latency applications.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
NebulOuS Meta Operating System and Platform	NebulOuS is on the path to pioneering a novel Meta Operating System (OS) and platform, forging a transformative approach to transient fog brokerage ecosystems. This addresses modeling, comparison, intelligent management, unified security, and smart contract-based SLA monitoring within the cloud computing continuum.	TRL6	MLP 2.0	Consortium of NebulOuS Project	Smart City; Smart Farming; Renewable energy, Disaster Management, Drone inspections	Edge, Cloud, IoT	**Resource Management, Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

NEMO

Efficient, reliable and secure end-to-end orchestration of hyper-distributed applications over programmable infrastructure that is spanning across the compute continuum from Cloud-to-Edge-to-IoT, removing existing openness and interoperability barriers in the convergence of IoT technologies against cloud and edge computing orchestration platforms, and introducing automation and decentralized intelligence mechanisms powered by 5G and distributed AI technologies.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Plugin Lifecycle Manager	The Plugin Lifecycle Manager (LCM) is a flexible mechanism for unified, just-in-time plugins and applications life cycle management across the NEMO ecosystem. The LCM is the interface between the NEMO ecosystem and the NEMO users, providing an interface for seamless deployment of workloads in the NEMO ecosystem while checking for updates and security related issues..	TRL4	Apache License 2.0	AEGIS IT RESEARCH	Smart Living; Smart City; Smart Factory;	Cloud	**Security**, **Resource Management, Observability**

Funded by Horizon Europe Framework Programme of the European Union

Secure Execution Environment for Mircroservices	The Secure Execution Environment for Microservices is a collection of enhancements for Kubernetes to increase the isolation and trust of the deployed services. Key components are the execution of Unikernels and confidential computing technologies.	TRL 4-5	MIT or BSD	RWTH	;	Cloud	**Security, Trust, Orchestration**
Monetization and Consensus-based Accountability (MOCA)	Consensus-based framework for accountability and monetization of transactions between NEMO providers and third-party consumers and partners	TRL 4, MRL 4	OSS (TBD)	MAGGIOLI	Not tested yet in specific domain;	Cloud	**Resource Management**
Intent-based META-OS API/SDK	NEMO exposure API&SDK through programmatic interfaces	TRL 4 and MRL 4	Open Source (TBD)	SYNELIXIS SOLUTIONS SA	Tested in lab so far;	?	**Orchestration**
Cybersecure distributed learning framework	Federating Learning framework supporting secure knowledge aggregation and transfer among untrusted peers	BOTH TRL & MRL: 4	Open Source	Netcompany Intrasoft	Tested on IDS data, which scenario applies to all verticals;	Cloud	**Security, Trust, Data Management**

Funded by Horizon Europe Framework Programme of the European Union

PRESS & Policy Enforcement Framework (PPEF)	Intent-based policy definition and enforcement framework for workload execution in the multi-cluster meta-OS environment	BOTH TRL & MRL: 4	Open Source	NEtcompany Intrasoft	Lab tests have been executed only so far;	Cloud	**Privacy, Monitoring, Observability**
Unified/Federated Access Control	Identity and Access Management's (IAM) system which role is to ensure that the right individual has access to the right resources	TRL 4 and MRL 4	Open Source	Synelixis Solutions SA	Smart Farming; Smart City; Smart Grid; Smart Factory;	?	**Security, Privacy, Trust**
Federated meta Network Cluster Controller	The Federated meta Network Cluster Controller provides transparent network connectivity, end-to-end (IoT-to-Edge-to-Cloud continuum)	TRL = 4	TBC	Several partners contributte to it (TID, UC3M, UPM)	Not yet tested in an integrated manner;	Edge, Cloud	**Security, Network, Monitoring**
Secure Intercommunicatio n Module	A secure message transferring module (based on RabbitMQ) and and an assosiated monitoring scheme.	TRL 4	Halg open-source, half Free for non-commercial use	Sphynx Technology Solutions Gmbh	It will be tested in Smart City, Smart Framing and Smart Factory settings as part of the	Cloud	**Monitoring**

Funded by Horizon Europe Framework Programme of the European Union

					NEMO project;		
Flower-based countermeasures for attacks on Federeated Learning	4 different countermeasures full implemented within the Flower network which will be tested in at least two different pilots within the NEMO project	TRL 4	open-source	NEMO	Smart Farming; Smart Factory;	Cloud	**Security**
meta-Orchestrator	The NEMO meta-Orchestrator simplifies the complexity of distributed computing in IoT to Edge to Cloud Continuum. It optimizes workflows for efficiency and ensures adaptability and interoperability. Overall, it addresses fundamental challenges and opportunities in this complex ecosystem, ensuring efficient workflow distribution and management.	From 4 to 6 (TRL)	Apache License 2.0	Atos	Not tested yet	Cloud, Edge, IoT	**Trust, Resource Management, Orchestration**
IoT/5G Time Sensitive Networking (TSN)	TSN features enable synchronizing mobile network UEs. TSN can be used to synchronize User	TRL 6	N/A	Cumucore Oy	Smart Factory;	Cloud, Edge, IoT	**Network**

Funded by Horizon Europe Framework Programme of the European Union

	Equipment in the mobile network with fixed IT infrastructure						

NEPHELE

Efficient, reliable and secure end-to-end orchestration of hyper-distributed applications over programmable infrastructure that is spanning across the compute continuum from Cloud-to-Edge-to-IoT, removing existing openness and interoperability barriers in the convergence of IoT technologies against cloud and edge computing orchestration platforms, and introducing automation and decentralized intelligence mechanisms powered by 5G and distributed AI technologies.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
VOStack open-source Software Stack for the virtualization of IoT devices	A Virtual Object (VO) is considered as 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 as VOStack. The VOStack supports interaction with both physical IoT devices and edge/cloud computing orchestration	TRL4	Open source, MIT	NEPHELE consortium	Smart Building; Smart Factory;	IoT, Edge, Cloud	**Resource Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

	platforms. It has three main architectural layers namely: the Physical Convergence Layer, the Edge/Cloud Convergence Layer, and the Backend Logic Layer.						
Synergetic Meta-Orchestration Platform	The NEPHELE Synergetic Meta-Orchestration Platform supports orchestration of distributed applications over multi-cluster environments, following an intent-driven approach. A high-level intent is translated into deployment and operational policies that manage the lifecycle of distributed applications, while taking advantage of AI/ML techniques for increasing automation and distributed intelligence.	3	Open source	NEPHELE consortium	Smart Building;	IoT, Edge, Cloud	**Resource Management, Orchestration, Artificial Intelligence**
NEPHELE Development Environment for Distributed Applications	The NEPHELE Development Environment is built as the combination of several systems; 1) The Highly Distributed Applications (HDA) Registry & Verification Engine which offer a novel way of harmonizing the storage, distribution and verification pipelines for the artifacts from the telco, cloud-native and custom Nephele ecosystems. 2)	4	Open source	NEPHELE consortium	Smart Building;	IoT, Edge, Cloud	**Resource Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

	The development sandbox provides specialized utilities and an intuitive dashboard to develop and customize HDA graphs which natively connect to the lifecycle management of those applications over multi-cluster compute and network infrastructure.						

Funded by Horizon Europe
Framework Programme of the European Union

TERMINET

Reference architecture to simplify the connection of a vast number of different devices through a flexible SDN-enabled middleware layer.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
A Centralised Federated Learning System (CFLS) for NG-IoT applications	The CFLS has been developed by University of Western Macedonia, achieving TRL 6 at the end of TERMINET. CFLS is a tool that enables federated model training in a user-centric manner, focusing on the needs and requirements of the end-users. The main innovation is that it has been developed to accommodate the Cloud-Edge environment, so it can quickly deploy local training on the edge devices and orchestration on the cloud. It was successfully used in four use cases of TERMINET.	TRL6	Commercial	University of Western Macedonia	Smart Building; Smart Farming; Smart Health, Supply Chain Forecasting;	IoT, Edge, Cloud	**Data Management, Orchestration, Artificial Intelligence**
An implementation of RINA technology for IoT devices	RINA-enabled IoT device incorporates the advantages of the RINA protocol such as flexibility, scalability, and adaptability to different networking scenarios. The RINA for IoT devices needs the IoT gateway to form a	TRL4	ASLv2	Fundació i2CAT	Smart Building;	IoT	**Network**

Funded by Horizon Europe Framework Programme of the European Union

	complete solution. It has been developed by i2CAT and has reached a TRL equal to 4. It's important to keep in mind that RINA is still evolving, and widespread adoption likely requires further development, standardization, and real-world testing.						
An implementation of RINA technology for IoT gateway	The RINA-enabled IoT gateway allows the IoT devices to communicate with each other using the RINA protocol. It has been developed (as EI03) from i2CAT and reached TRL 5. It's important to keep in mind that RINA is still evolving, and widespread adoption likely requires further development, standardization, and real-world testing.	TRL5	Open source	Fundació i2CAT	Smart Building;	IoT	**Network**
A cloud-level application orchestrator for microservices on top of public or private cloud infrastructures	The Vertical Application Orchestrator (VAO) is a cloud-level application orchestrator platform that allows to easily onboard, deploy, and manage cloud microservices on top of public or private cloud infrastructures. It has been developed by UBITECH and has reached TRL 7 at the end of TERMINET.	TRL7	Commer cial	UBITECH	Smart Building; Smart Farming; Smart Healthcare, Group Training Surgery Using VR-enabled IoT Technologies, Supply Chain Forecasting, Mixed Reality	Cloud, Edge	**Orchestration**

					and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure.		
An SDN-enabled container network interface (CNI) for establishing an SDN-based network substrate underneath Kubernetes	The CNI has been developed by UBITECH and has reached TRL 7. It is targeted to cloud service providers and provides a programmable network fabric which dynamically interconnects Kubernetes microservices. The developed solution relies on open-source tools developed by the global networking community and establishes an end-to-end SDN between IoT devices and TERMINET applications which offers (I) traffic visibility and (ii) traffic steering through a unified SDN control plane using open APIs.	TRL7	Open source	UBITECH	Smart Building; Smart Farming; Smart Healthcare, Dairy Supply Chain Forecasting, Group Training Surgery Using VR-enabled IoT Technologies, Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure ;	Cloud, Edge, IoT	**Network**

Funded by Horizon Europe Framework Programme of the European Union

A Federated Learning Acceleration Unit (FLAU) for reduced latency and of increased privacy and security levels of conventional Edge Computing	The FLAU is using FPGA (Field-Programmable Gate Array) hardware acceleration for Federated Learning. It was developed by Future Intelligence and has achieved TRL 6. Boosted Edge Computing not only enjoys the benefits of reduced latency and of increased privacy and security levels of conventional Edge Computing (no need to transfer, process and/or store data to cloud/central data centers), but also leverages hardware acceleration in terms of computing speed and/or lower energy consumption.	TRL6	Commercial	Future Intelligence Ltd.	Smart Building; Smart Farming; Smart Healthcare, Dairy Supply Chain Forecasting, Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure, Group Training Surgery Using VR-enabled IoT Technologies;	Edge	**Security, Privacy, Data Management**
A Platform Data Management Ledger (PDML) for Blockchain deployments in NG-IoT applications	The PDML consists of a Blockchain Network, which is a Hyperledger Fabric instance and 2 services in the form of smart contracts. The first contract is a logging system, bringing auditability to the system. The second contract is an authorization framework, where an administrator can revoke access to resource owners that are having	TRL6	Commercial	Centre of Research and Technology Hellas (CERTH)	Smart Building; Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure,	IoT	**Security, Privacy, Trust, Data Management, Network**

	suspicious behaviour. It was developed by Centre for Research and Technology-Hellas with TRL6.				Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products;		
A secure, distributed and trusted data sharing framework (DSF) that emphasizes individuals' control over their own personal information.	The DSF is a standalone service that allows for TERMINET end-users to share data pieces they own, with explicit rules for sharing and legally binding agreements. It was developed by Centre for Research and Technology-Hellas and has reached TRL 6.	TRL6	Commercial	Centre of Research and Technology Hellas (CERTH)	Smart Building; Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products, Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure;	Cloud, Edge, IoT	**Privacy**
A QR Scanner Application for displaying information on Augmented Reality glasses	A smart application which scans QR codes retrieves information and provides the ability to execute various actions such as automatic guidelines providing to a field engineer for Remote Terminal Units and Small	TRL7	Open source	Eight Bells	Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based	IoT	**Artificial Intelligence**

for Predicative Maintenance applications	Form-factor Pluggable units maintenance. It has been developed by Eight Bells while, Public Power Corporation S.A. was involved as an end user and OPTINVENT provided the hardware (ORA-2 smart glasses). It has TRL7.				Critical Infrastructure;		
An Analytic Toolset for Accurate Forecasting (ATF) of Dairy Products	The ATF is a software component that forecasts the expected production of products in a factory based on the previous years. It has been developed by Eight Bells to assess the production expectations of MEVGAL in TERMINET's UC4. Is has TRL 5. This tool envisions to optimize the production volume of products and reduce the amount of wasted products and has as target end-users' industries that produce dairy products, while also food related industries can also be considered as potential customers.	TRL5	Open access	Eight Bells	Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products;	Cloud, Edge, IoT	**Monitorin, Artificial Intelligence**
A Secure Federated Machine Learning Framework	The FML provides a decentralized environment for a secure data training following a data centric security approach in which advanced cryptographic techniques (such as Multiparty Computation) are used for	TRL5	Commer cial	Tecnalia Research and Innovation	Pathway of Personalised Healthcare (Smart Healthcare), Group Training	IoT, Cloud	**Privacy, Data Management, Artificial Intelligence**

(FML) for NG-IoT applications	improving confidentiality. Tecnalia Research and Innovation is the owner of this innovation and the TRL level is 5.				Surgery Using VR-enabled IoT Technologies;		
A Clinical Dashboard (HLT Dashboard) for Healthentia platform for remote patient monitoring	The HLT Dashboard combines clinical data from hospitals' infrastructure with Healthentia Platform behavioural data in dashboards visualised within the Healthentia portal application, when invoked from within the hospitals' networks. It has been developed by Innovation Sprint Sprl, reaching TRL 7.	TRL7	Commercial	Innovation Sprint srl	Pathway of Personalised Healthcare (Smart Healthcare);	IoT, Edge, Cloud	**Data Management, Network, Monitoring**
ORA2 Augmented Reality Smart glasses for Smart Farming and Predictive Maintenance Applications	The OPTINVENT ORA-2 is a professional-grade smart glasses that has reached TRL9 and features a unique "Flip-Vu" display, allowing you to switch between Augmented Reality and "glance" modes. It comes with its own flexible Android SDK for developing apps and fine-tuning the user experience.	TRL9	No licensing on hardware technology, selling of hardware (display &	OPTINVENT	Smart Farming	IoT	**Data Management,**

			glasses) and license of softwar e/applic ation				
New Generation of Remote Terminal Unit (RTU) device for advanced control and monitoring in Critical Infrastructures	This is an Electrical infrastructure Intelligent Electronic Device (IED) for advanced control and monitoring that has been developed by Schneider Electric, the achieved TRL is 7.	TRL7	Commer cial	Schneider Electric	Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure	IoT	**Monitoring**
A Remote Terminal Unit (RTU) Communication Interface for secure IoT connections	The developed solution is a software tool that provides secure IoT connections to RTU, it has been developed by Schneider Electric and the TRL level achieved is 6.	TRL6	Commer cial	Schneider Electric	Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure	IoT	**Monitoring, Observability, Artificial Intelligence**

A Local Learning Services (LLS) for AI Model Learning at the Edge for Decentralised Infrastructures in Smart Healthcare Applications	The LLS, developed by Innovation Sprint Sprl, having TRL 7, facilitates model learning at the edge, in cases where data cannot be centralized. To do so, LLS composes vectors of joint behavioural and clinical data for Machine Learning. It also learns generative models and synthesized data to produce hybrid actual/synthetic data sets for ML.	TRL7	Commercial	Innovation Sprint Sprl	Pathway of Personalised Healthcare (Smart Healthcare)	IoT	**Data Management, Artificial Intelligence**
A customizable Clinical Dashboard theming for the Healthentia platform facilitating Smart Healthcare Applications	Healthentia (HLT) app theming is the ability to change aspects of the theme such as colors, banner etc. making it customized to each of the clinical studies and having a unique design. It was developed by Innovation Sprint Sprl for the Healthentia app, reaching TR7. The Healthentia mobile app can be themed with custom banner graphics and colours per study, giving the impression the app is designed for the particular study.	TRL7	Commercial	Innovation Sprint Sprl	Pathway of Personalised Healthcare (Smart Healthcare)	IoT	**Observability**

Funded by Horizon Europe Framework Programme of the European Union

A Local Data Connector (LDC) for data visualization at the Edge for Decentralised Infrastructures in Smart Healthcare Applications	The LDC, developed by Innovation Sprint Sprl, having TRL 7, facilitates delivery of data at the edge for visualization to a centralized clinical dashboard. It is deployed at the edge (hospital premises) in cases where the clinical data cannot be ingested into the central data repository. It abstracts the details of the Hospital Information Systems, by obtaining the data and formatting it into the expected format of the clinical dashboard.	TRL7	Commercial	Innovation Sprint Sprl	Pathway of Personalised Healthcare (Smart Healthcare)	Edge	**Data Management**
An Augmented Reality-assisted End-to-End Smart Precision and Smart Animal Monitoring Platform (AGROMINDS) for achieving sustainability in agricultural operations	The AGROMIND Dashboard is an advanced data visualization dashboard designed to aid the producers keep track of field operations and status of their infrastructure while helping them achieve their production goals. It was developed by University of Western Macedonia. The achieved TRL is 6.	TRL6	Commercial	University Of Western Macedonia	Smart Farming	?	**Observability**

Funded by Horizon Europe Framework Programme of the European Union

An SDN Controller and custom-tailored SDN dashboard able to provide a fault-tolerant and scalable control plane suitable for edge environments.	The SDN Controller and Dashboard is a python-based SDN controller accompanied by a custom-tailored SDN dashboard able to provide a fault-tolerant and scalable control plane suitable for edge environments. It was developed by University of Western Macedonia and the achieved TRL is 6.	TRL6	Commer cial	University Of Western Macedonia	Smart Living; Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure;	Edge	**Network, Monitoring**
An innovative platform (FINoT Platform) for merging the conventional M2M with the emerging IoT	The FINoT Platform is designed in order to merge the conventional M2M with the emerging IoT world using a standards-based approach with strong focus on industrial and semi-industrial applications. Through the platform, it is possible to connect almost any kind of sensor or actuator in a plug-and-play manner, making it possible to use immediately. It has been developed and owned by Future Intelligence and the TRL is 7.	TRL7	Commer cial	Future Intelligence Ltd.	Smart Farming; Smart Building; Smart Healthcare, Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products, Group Training Surgery Using VR-enabled IoT Technologies, Mixed Reality and ML	IoT	**Resource Management, Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

					Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure;		
A Bootstrapping Trust and Integrity Measurement Tool (BIM) for remote attestation services	The BIM provides remote attestation services allowing checks remotely the integrity of devices and nodes. The runtime integrity measurements comprise the boot chain (UEFI, OS, drivers, etc.) of a node and other running software and configurations. Root of trust leverages the presence of TPM 2.0 HW chip in the attester environment. It has been developed and owned by Ericsson Telecomunicazioni SpA and the TRL is 6.	TRL6	Apache 2.0	Ericsson Telecomunicazioni	Smart Farming; Smart Building; Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure, Smart Healthcare, Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products, Group Training Surgery Using	Cloud, Edge, IoT	**Trust**, **Monitoring**

Funded by Horizon Europe Framework Programme of the European Union

					VR-enabled IoT Technologies;		
An Intelligent Intrusion Detection System for safeguarding security in NG-IoT applications	The IDS is a distributed security monitor tool that is composed of many ids processes but acts as a single entity. The network traffic is being sliced and distributed across the workers that are sniffing the same interface, using flow-based load balancing techniques, to perform deep packet inspection and protocol analysis on the captured packets. LOGOS Research and Innovation has developed it and the TRL is 6.	TRL6	Open source	LOGOS Research and Innovation	Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure;	IoT	**Security, Privacy, Network**
A Radio-Frequency Energy Harvesting Prototype System for IoT devices as a prospective alternative energy source	The RF Energy Harvesting prototype system includes a transmitting antenna, focused on the wireless power transfer of electromagnetic radiation. It also includes a receiving module, i.e., a rectenna (antenna + rectifier), to harvest the electromagnetic radiation and convert it to DC power. It was fabricated and experimentally validated using low-	TRL4	None	Aristotle University of Thessaloniki	Smart Farming;	IoT	**Data Management, Resource Management**

for future applications	cost materials. The RF energy harvesting prototype is a hardware developed by the Aristotle University of Thessaloniki with achieved TRL 4.						
An IoT Digital Twin Environment (IoT-DTE) for strict latency industrial internet of things (IIoT) scenarios	The IoT-DTE is a distributed, cloud native architecture tasked with data gathering and lightweight processing at the decentralized edge cloud with pluggable (infrastructure) support for strict latency industrial internet of things (IIoT) scenarios. University of Bologna is the owner of this innovation and the TRL achieved is 6.	TRL6	Open Source	University of Bologna	Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure;	Cloud, Edge, IoT	**Data Management**
A novel Attestation Gateway (AG) acting as middleware for employing remote attestation services.	The AG provides a unifying process to remotely attest devices and services by acting as a middleware between the involved entities, namely, the attesters, the provers, and the verifiers. To this end, AG exposes an API to the attesters that aims at simplifying the attestation process in systems that are composed out of a multitude of diverse devices and services, located at different sites and running on different platforms. The AG has been	TRL4	Commer cial	NEC Corporation	Smart Farming; Smart Building; Pathway of Personalised Healthcare (Smart Healthcare), Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products,	Cloud, Edge, IoT	**Orchestration, Monitoring**

	developed by NEC Corporation and the TRL is 4.				Group Training Surgery Using VR-enabled IoT Technologies, Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure;		
A POLIcy MONitor (POLIMON) for policy compliance, and enforcement in NG-IoT applications	The POLIMON monitors system behaviour and checks it in real time against system and security policies given in a rich temporal logic based specification language. Policy violations are reported promptly by maintaining a state that consists of a novel graph-based data structure that is efficiently updated for each received system action. It has been developed by NEC Corporation and the TRL is 5.	TRL5	Commer cial	NEC Corporation	Smart Farming; Smart Building; Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure, Pathway of Personalised Healthcare (Smart Healthcare),	Edge, IoT	**Security**, **Monitoring**

Funded by Horizon Europe Framework Programme of the European Union

					Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products, Group Training Surgery Using VR-enabled IoT Technologies;		
A softwaRe fOr impacT Assessment (ROTA) in NG-IoT applications, identifying potential risks and vulnerabilities, facilitating the implementation of effective mitigation strategies.	ROTA is a tool for identifying potential risks and vulnerabilities, facilitating the implementation of effective mitigation strategies. The reached TRL is 4 and the tool has been developed by SIDROCO Holdings Ltd. The proposed mechanism was used to create an easy-to-use GDPR compliance process, primarily aimed for SME/ME data controllers but enhanced to make Privacy Impact Assessment (PIA) Process even simpler for small organizations.	TRL4	Open source	SIDROCO Holdings Ltd	Smart Farming; Smart Building; Pathway of Personalised Healthcare (Smart Healthcare), Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products, Group Training Surgery Using VR-enabled IoT Technologies,	IoT	**Security**, **Privacy**

					Mixed Reality and ML Supported Maintenance and Fault Prediction of IoT-based Critical Infrastructure		

VEDLIOT

IoT platform that uses deep learning algorithms distribute throughout the IoT continuum.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Cognitive IoT Platform + Microservers	The Cognitive IoT Platform consists of different hardware substrates, e.g. the RECS|Box Durin and the t.RECS as well as the newly developed u.RECS. All platforms share a common vision, to enable heterogeneous computing using x86, ARM, GPU, FPGA or AI acceleration units. The different prototypes range from the cloud to the edge domain, offering different performance classes. All hardware	TRL 6	Commer cial	VEDLIoT	Smart Living; Smart Factory; Smart Vehicle;	IoT	**Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

	substrates are designed to target the growing need for fast (AI-enabled) data processing and energy efficiency in those respective domains. All Cognitive IoT Platforms make use of standardized industrial server on modules (microservers). This results in a reduced TCO, because the overall lifetime of the platforms themselves are extended while only microservers have to be exchanged to adapt to newer technologies. In VEDLIoT, a microserver with an FPGA/ARM and an embedded AI accelerator was developed, based on the industrial SMARC form factor.						
Renode	Renode simulates entire SoC's and is able to use co-simulation with verilated CFU models to test the end-to-end flow of an ML application. This enables developers to test and optimize custom instruction sets implemented using Renode's CFU extension for ML tasks before implementing them in hardware.	7	Open (MIT)	VEDLIoT	Smart Factory; Smart Living; Smart Grid; Smart Farming; Smart Vehicle; Smart Building; Smart City;	Cloud, Edge, IoT	**Artificial Intelligence**

Smart Mirror	The Smart Mirror envisions a future where seamless integration of object, gesture, and face recognition transforms daily routines. Beyond showcasing the effortless synergy with RECS hardware, it stands as a visionary demonstration of embedded machine learning applications. Within the academic realm, the smart mirror becomes a gateway to unlocking the full potential of embedded machine learning. It transcends theoretical lectures, providing students with hands-on experiences through engaging projects. The practical application of knowledge using the smart mirror propels the boundaries of embedded machine learning, offering students a profound understanding of the concepts and their real-world implications.	6	Open	VEDLIoT	Smart Building; Smart Living;	Cloud, Edge, IoT	**Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

TRANSACT

Universal distributed solution architecture for the transformation of safety-critical CPS from local, stand-alone systems into safe and secure distributed solutions.

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
TRANSACT Reference Architecture	A Reference Architecture to help organizations migrate safety-critical cyber-physical systems from monolithic approaches to distributed solutions, while ensuring safety, performance, security and privacy.	N/A	N/A	TRANSACT consortium	Smart Vehicle; Maritime, Electric Vehicles, Wastewater Treatment Plants, Healthcare;	Cloud, Edge, IoT	**Security**
TRANSACT Transition Guide	A methodology for transforming local, monolithic, safety-critical cyber-physical systems (CPS) into distributed, safety-critical solutions deployed across the device edge cloud continuum.	N/A	N/A	TRANSACT Consortium	Smart Vehicle; Maritime, Electric Vehicles, Wastewater Treatment Plans, Healthcare	Cloud, Edge, IoT	**Security**

AEROS

Meta operating systems that follows a collaborative IoT-edge-cloud architecture supporting flexible deployments to achieve and optimal solution while satisfying the given constrings.

Funded by Horizon Europe Framework Programme of the European Union

Name of the asset	Short description	TRL and MRL	License	Owner - organization	Domain(s) where tested	OC TAG LEVEL 2	OC TAG LEVEL 3
Multi-layer orchestration stack for the IoT Edge Cloud Continuum (aerOS Orchestration Stack)	The aerOS orchestration stack comprises two-level orchestrator components with a decision engine (High-level-orchestrator) separate from the enforcement layer (LLOs). HLO (AI-powered) orchestrates computing resources over any runtime on top of the continuum. It, in turn, relies on offloading the workload to LLOs, that via CRD requests interact with the underlying container management. Integrating AI, trust services, and federation enhances distributed decision-making for efficient workload placement.	4-4	Not decided yet. Open license (a type of Open Source Software License)	NCSRD, UPV, ICT-FI	Smart Building; Smart Factory; Smart Farming; Smart Grid; In current tests	Cloud, Edge, IoT	**Orchestration**
Federated data fabric enabling seamless usage of information anywhere and	The Data Frabric targets the distributed data management within a continuum, with data as a product methodology, includes tools like data catalogue, data security, privacy, data annotation and translation, with advanced access policies ensuring data governance..	3-4	Not decided yet. Open license (a type of Open Source Software License)	TID, UPM, FIWARE FOUNDATION	Smart Farming; Smart Building; Smart Factory	Cloud, Edge, IoT	**Security, Privacy, Data Management**

Funded by Horizon Europe Framework Programme of the European Union

anytime (aerOS Data Fabric)	Security, privacy, and automated adjustments are crucial in the current challenges in the field, needing interdisciplinary approaches like aerOS.						
DevPrivSecOps - CI/CD innovative methodology including Privacy and Security in the DevOps process	The proposed methodology for CI/CD and scripts for pipelines implementation, plus software tools to support private, secure lifecycle management of aerOS components. Process and data flow, including techniques and open source technologies that, combined, improve current DevSecOps de-facto methodological standards, and go beyond the state of the art of DevSecOps and take a leap forward by adding privacy needs, allowing developers to create secure and privacy aware software by design.	6-8	Not decided yet.	S21Sec	It has not been introduced in the pilots yet.	Cloud, Edge, IoT	**Security, Privacy**
Continuum Data Model supporting data autonomy for homogeneizati on (aerOS	A novel data model for expressing the status of the continuum (resources, network, services, domains…). The innovation opens up the possibility of federation, ubiquitous access, and exploitation of information of the continuum. These approaches enable	5-6	Not decided yet. Open license (a type of Open Source Software License)	UPV	Smart Building; Smart Farming; Smart Grid; Smart Factory; Maritime Transport	Cloud, Edge, IoT	**Data Management**

Continuum Data Model)	aerOS to homogenize data models at the edge, facilitating seamless integration and utilization of heterogeneous data sources while maintaining autonomy and privacy.						

Funded by Horizon Europe Framework Programme of the European Union

ANNEX 2: OPEN SOURCE PROJECTS

As well as Annex 1, this section contains the list of the most commonly used open source projects by research ones. This list is not exclusive, as other projects may make use of another ones, however, it is the most representative one for the purpose of this analysis.

The structure of the information is as follows:

- *Project:* to easily identify the project.
- *Project description:* of the functionalities provided justifying for what the project is useful for.
- *License:* to identify the compatibilities of the licensed software with other components.
- *Owner:* the community or organization where the project belongs to.
- *OC tag level 2 and 3:* to map results with the reference architecture in order to identify gaps and challenges.

Project	Project description	License	Owner / organization	OC TAG LEVEL 2	OC TAG LEVEL 3	
Eclipse 4diac™	Eclipse 4diac™ in its current form has been started 2007 as an open source project fostering the further development of IEC 61499 Standard for its use in distributed Industrial Process Measurement.	EPL	ECLIPSE	IoT	**Data Management**	
Eclipse Agail	The Eclipse Agail is a language-agnostic, modular software and hardware gateway framework for the Internet of Things with support for protocol interoperability, device and data management, IoT application execution, trusted data sharing and external Cloud communication.	EPL	ECLIPSE	Open Source	IoT	**Trust, Data Management**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Amlen	Eclipse Amlen™ is a scalable, secure, easy to use message broker that can be used for IoT, web and mobile use-cases. It primarily supports the MQTT protocol (v5 and v3.x) but supports JMS and custom protocols as well.	EPL	ECLIPSE	Open Source	IoT	**Security**
Eclipse Arrowhead	Eclipse Arrowhead is a framework and implementation platform to build automation and digitalisation solutions. The basis is an microservice and micro system architecture utilising service-oriented architecture principles. The implementation platform includes an engineering process and associated tools and core microsystems. Well proven core microsystem, libraries and template code for application systems, support for model-based engineering using SysML and UML are available open source.	EPL	ECLIPSE	Open Source	IoT	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse BaSyx™	Eclipse BaSyx™ implements an open-source Industry 4.0 middleware based on the Asset Administration Shell that enables the shopfloor digitization. Eclipse BaSyx is the open source platform for next generation automation. It implements key concepts defined by Platform Industrie 4.0, such as the Asset Administration Shell as standardized digital twin. Eclipse BaSyx therefore provides common and re-useable off-the shelf Industrie 4.0 components and SDKs (Java, C# and C++) that support the implementation of new Industrie 4.0 software components to enable rapid development of Industrie 4.0 solutions.	EPL	ECLIPSE	Open Source	IoT	**Data Management, Observability, Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Californium™ (Cf) CoAP Framework	Eclipse Californium™ (Cf) is an open source implementation of the Constrained Application Protocol (CoAP). It is written in Java and targets unconstrained environments . The project is divided into five sub-projects. The Californium (Cf) Core provides the central framework with the protocol implementation to build your Internet of Things applications. The repository also includes example projects to get you started. All Californium sources are hosted on GitHub, so you can easily contribute through pull requests.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**
Eclipse Codewind	The Cloud Foundry Tools are not specialized to just work with a specific Cloud Foundry platform. It allows users to set various Cloud Foundry targets, may it be public Cloud Foundry-based platforms like Pivotal Web Services, IBM Bluemix, or others	EPL	ECLIPSE	Open Source	Cloud	**Resource Management, Orchestration**
Eclipse Concierge	Concierge is a small-footprint implementation of the OSGi Core Specifications R5 standard optimized for mobile and embedded devices.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Cyclone DDS™	**Eclipse Cyclone DDS™ is an implementation of the OMG Data Distribution Service (DDS) specification (see http://www.omg.org/spec/DDS) and the related specifications for interoperability.**	**EPL**	**ECLIPSE**	**Open Source**	**IoT**	**Data Management**
Eclipse Ditto™	Eclipse Ditto™ is a framework for providing the "Digital Twin" pattern for IoT applications in order to interact with IoT devices. Eclipse Ditto is an open source framework helping you to build digital twins of devices connected to the internet.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**

Eclipse Edje	The edge devices connected to the Cloud that constitute the Internet of Things (IoT) require support for building blocks, standards and frameworks like those provided by the Eclipse Foundation. The goal of the Edje project is to define a standard high-level Java API called Hardware Abstraction Layer (HAL) for accessing hardware features delivered by microcontrollers such as GPIO, DAC, ADC, PWM, MEMS, UART, CAN, Network, LCD, etc. that can directly connect to native libraries, drivers and board support packages provided by silicon vendors with their evaluation kits.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**
Eclipse fog05	Eclipse fog05 provides a virtualised infrastructure that allows to distribute computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum. From this description it should be clear that fog05 can leverage cloud infrastructure or equally function without it.	EPL	ECLIPSE	Open Source	IoT	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Gran Sasso	Eclipse Gran Sasso is a pilot project that predicts performance of cloud-native enterprise Java applications and traditional application servers using AI/ML techniques.	EPL	ECLIPSE	Open Source	Cloud	**Observability, Artificial Intelligence**
Eclipse Hara	Eclipse Hara™ provides a reference agent software implementation featuring the Eclipse hawkBit device API.Such reference implementations are initially driven by operating systems and application frameworks that today constitute the main platforms for the majority of IoT and embedded devices. These devices include but are not limited to: Open Embedded, Android, QT, etc. The scope of the project is to fill the gap that was intentionally left out by the hawkbit project. The purpose is to provide device update management and client solutions for handling software updates on the device. By providing a solid open source reference implementations of a hawkBit client, which is driven by the fundamental use cases for updating a remote device, the project can be beneficial toward the adoption of the hawkBit update server as a backend solution.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**

Funded by Horizon Europe
Framework Programme of the European Union

Eclipse hawkBit	Eclipse hawkBit™ is a domain independent back-end framework for rolling out software updates to constrained edge devices as well as more powerful controllers and gateways connected to IP based networking infrastructure.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**
Eclipse Hono	Eclipse Hono™ provides remote service interfaces for connecting large numbers of IoT devices to a back end and interacting with them in a uniform way regardless of the device communication protocol.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**
Eclipse JKube™	Cloud-Native Java Applications without a hassle.Eclipse JKube is a collection of plugins and libraries that are used for building container images using Docker, JIB or S2I build strategies. Eclipse JKube generates and deploys Kubernetes/OpenShift manifests at compile time too.	EPL	ECLIPSE	Open Source	Cloud	**Orchestration**
Eclipse Kanto	Eclipse Kanto™ is a modular IoT edge software that enables devices for IoT with all essentials like cloud connectivity, digital twins, local communication, container management, and software updates - all configurable and remotely manageable by an IoT cloud ecosystem of choice.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Keti	Keti is a service that was designed to protect RESTfuls API using Attribute Based Access Control (ABAC). The solution itself is implemented as a cloud-native RESTful API that adheres to the guiding principles of the twelve factor app.	EPL	ECLIPSE	Open Source	IoT	**Security**
Eclipse Kura™	Eclipse Kura™ is an extensible open source IoT Edge Framework based on Java/OSGi. Kura offers API access to the hardware interfaces of IoT Gateways (serial ports, GPS, watchdog, GPIOs, I2C, etc.). It features ready-to-use field protocols (including Modbus, OPC-UA, S7), an application container, and a web-based visual data flow programming to acquire data from the field, process it at the edge, and publish it to leading IoT Cloud Platforms through MQTT connectivity.	EPL	ECLIPSE	Open Source	IoT	**Data Management**
Eclipse Milo	an open source implementation of OPC UA (IEC 62541).It defines the interface between Clients and Servers, including access to real-time data, monitoring of alarms and events, historical data access, and data modeling.	EPL	ECLIPSE	Open Source	IoT	**Data Management**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Mosquitto™	Eclipse Mosquitto provides a lightweight server implementation of the MQTT protocol that is suitable for all situations from full power machines to embedded and low power machines. Sensors and actuators, which are often the sources and destinations of MQTT messages, can be very small and lacking in power. This also applies to the embedded machines to which they are connected, which is where Mosquitto could be run.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**
Eclipse OM2M	The Eclipse OM2M project, initiated by LAAS-CNRS, is an open source implementation of oneM2M and SmartM2M standard. It provides a horizontal M2M service platform for developing services independently of the underlying network, with the aim to facilitate the deployment of vertical applications and heterogeneous devices.	EPL	ECLIPSE	Open Source	IoT	**Network**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Oniro	The mission of the Eclipse Oniro Top-Level Project is the design, development, production and maintenance of an open source software platform, having an operating system, an ADK/SDK, standard APIs and basic applications, like UI, as core elements, targeting different industries thanks to a next generation multi-kernel architecture, that simplifies the existing landscape of complex systems, and its deployment across a wide range of devices.	EPL	ECLIPSE	Open Source	IoT	**Orchestration**
Eclipse Oniro Blueprints	Creating blueprints has many advantages for the Oniro Project.	EPL	ECLIPSE	Open Source	IoT	**Orchestration**
Eclipse Oniro Compliance Toolchain	Eclipse Oniro Compliance Toolchain implements a Continuous Compliance workflow for Oniro repositories.	EPL	ECLIPSE	Open Source	IoT	**Orchestration**
Eclipse Oniro Core Platform	Eclipse Oniro Core Platform™ is an open-source project aimed at reducing fragmentation in the consumer and IoT device industry which is interoperable with OpenAtom Foundation's OpenHarmony project.	EPL	ECLIPSE	Open Source	IoT	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse OpenCert	Eclipse OpenCert is a customizable safety assurance and certification tool environment integrated into existing manufacturers' development and safety assurance processes and tooling. The OpenCert tools support the activities of safety-critical product development.	EPL	ECLIPSE	Open Source	IoT	**Security**
Eclipse OpenSmartCLIDE	The SmartCLIDE project enables organizations on the path to digitalization to accelerate the creation and adoption of Cloud solutions. The innovative smart cloud-native development environment supports creators of cloud services in the discovery, creation, composition, testing, and deployment of full-stack data-centered services and applications in the cloud.	EPL	ECLIPSE	Open Source	Cloud	**Orchestration**

Funded by Horizon Europe
Framework Programme of the European Union

Eclipse Safety Framework	The Eclipse Safety Framework (ESF) project provides a set of tools that enable both modelling and analysis of safety concerns in the context of modelling standards such as SysML and MARTE. ESF allows a first-class interactivity between design and safety assessment activities. A dysfunctional model is built from the system model denoted using SysML. It is used to specify possible failure-modes, mitigation barriers, and propagation behaviour at components level. This is the manual local analysis. From the specification of feared events (expressed in safety requirements), an automatic global analysis can then produce propagation paths and corresponding fault trees. The dysfunctional model can be improved in an iterative way, until the safety requirements are fully satisfied. Finally, reports can be exported in different formats (e.g., HTML and PDF) to document the analyses hypothesis and results. Athis approach is based on models, each time the system model evolves, a new safety analysis can be done on the modified	EPL	ECLIPSE	Open Source	IoT	**Security**

Funded by Horizon Europe
Framework Programme of the European Union

	parts, and keeps the previous analysis on each unchanged component.					
Eclipse Time4Sys	PolarSys Time4Sys provides a framework that fills the gap between the capture of timing aspects in the design phase of a real-time system and the ability of specific/dedicated tools to verify the consistency and performances of a given scheduling. Time4Sys is composed of two building blocks (the Design and the Analysis pivot models) as well as a set of transformation rules between them.	EPL	ECLIPSE	Open Source	IoT	**Observability**
Eclipse Tocandira	Eclipse Tocandira is a collection of tools aiming to help industries to remove their barriers on observability. To achieve this goal it uses the cutting edge technologies in the field. You will find the deploy easily configured with Docker, the connectivity with PLCs powered by 4diac, the gathering and storage done by Prometheus and the visualization shown with Grafana.	EPL	ECLIPSE	Open Source	IoT	**Observability**

Funded by Horizon Europe
Framework Programme of the European Union

Eclipse Tools for Cloud Foundry	Eclipse Tools for Cloud Foundry (CFT) provide an extensible framework and common UI to deploy applications to different Cloud Foundry targets, and it is a framework that closely integrates with Web Tools Platform (WTP) and Eclipse. It allows application scaling and services management from the same Eclipse-based IDE where applications are developed. Applications can also be debugged on Cloud Foundry using the built-in Eclipse debugger. This makes it very convenient for developers to work on applications running on CF.	EPL	ECLIPSE	Open Source	Cloud	**Orchestration**

Funded by Horizon Europe
Framework Programme of the European Union

Eclipse UPM	The Eclipse UPM project builds on the solutions of MRAA. While the MRAA project provides an abstraction layer for several IoT platforms, offering developer access to the physical pins and buses, UPM supplies developers with C/C++ sensor libraries with bindings to Java*, JavaScript* and Python*. UPM makes it easier to interface with the sensors bundled with the Intel® IoT Developer Kits and extends the MRAA library. The UPM sensor libraries use MRAA I/O classes in order to expose an API abstraction that simplifies the interaction between developers and peripherals. The UPM APIs provide consistent, standardized access to the supported devices with over 400 different sensors, actuators and radio modules currently supported.	EPL	ECLIPSE	Open Source	IoT	**Resource Management**
Eclipse Xpanse	Eclipse Xpanse provides a framework to describe and deploy cloud managed services to enable anyone to create them in a open and portable way.	EPL	ECLIPSE	Open Source	Cloud	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Eclipse Zenoh	Zenoh /zeno/ is a pub/sub/query protocol unifying data in motion, data at rest and computations. It elegantly blends traditional pub/sub with geo distributed storage, queries and computations, while retaining a level of time and space efficiency that is well beyond any of the mainstream stacks.	EPL	ECLIPSE	Open Source	IoT	**Data Management**
Kubernetes	Kubernetes is an open source system for automating deployment, scaling and management of containerized applications.	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
Open Source MANO	Open Source MANO is an ETSI-hosted project to develop an Open Source NFV Management and Orchestration (MANO) software stack aligned with ETSI NFV.	Apache 2.0	ETSI	Open Source	Edge, Cloud	**Orchestration, Network**
Submariner	Submariner enables direct networking between pods and services in different Kubernetes clusters, either on-premises or in the cloud.	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
KubeSphere	An open source Kubernetes platform to manage enterprise-grade Kubernetes across hybrid cloud, multi-cloud and edge.	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
Rancher Fleet	Fleet can manage deployments from git of raw Kubernetes YAML, Helm charts, Kustomize, or any combination of the three.	Apache 2.0	Rancher	Open Source	Edge, Cloud	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

OpenFaaS	OpenFaaS makes it easy for developers to deploy event-driven functions and microservices to Kubernetes without repetitive, boiler-plate coding.	MIT	CNCF	Open Source	Edge, Cloud	**Orchestration**
OpenWhisk	Apache OpenWhisk is an open source, distributed Serverless platform that executes functions (fx) in response to events at any scale	Apache 2.0	Apache	Open Source	Edge, Cloud	**Orchestration**
Kubedge	KubeEdge is an open source system for extending native containerized application orchestration capabilities to hosts at Edge.	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
OpenShift	OpenShift helps develop, deploy, and manage container-based applications. It provides you with a self-service platform to create, modify, and deploy applications on demand, thus enabling faster development and release life cycles.	Apache 2.0	Red Hat	Open Source	Edge, Cloud	**Orchestration**
Google GKE	Google Kubernetes Engine (GKE) is a managed Kubernetes service that can be used to deploy and operate large-scale containerised applications on Google's infrastructure.	Apache 2.0	Google	Open Source	Edge, Cloud	**Orchestration**
Kubeshift	Kubeshift is a multi-provider Python library for Kubernetes (kube) and Openshift (shift).	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

TensorFlow	End-to-end open source platform for machine learning to easily build and deploy ML-powered applications.	Apache 2.0	TensorFlow	Open Source	Edge, Cloud	**Artificial Intelligence**
OpenStack	Cloud operating system that controls large pools of compute, storage and networking resources throughout a datacenter, all managed and provisioned through APIs with common authentication mechanisms.	Apache 2.0	OpenInfra Foundation	Open Source	Cloud	**Orchestration**
Keras	Keras is an open source library that provides a Python interface for artificial neural networks.	Apache 2.0	Google	Open Source	Edge, Cloud	**Artificial Intelligence**
Scikit	Set of tools for predictive data analysis	BDS-3 Clause	Scikit	Open Source	Edge, Cloud, IoT	**Artificial Intelligence**
PyTorch	PyTorch is a machine learning library used for applications such as computer vision and natural language processing.	Caffe2	Linux Foundation	Open Source	Edge, Cloud, IoT	**Artificial Intelligence**
Liqo	Open source project that enables dynamic and seamless Kubernetes multi-cluster topologies, supporting heterogeneous on-premise, cloud and edge infrastructures.	Apache 2.0	Liqo	Open Source	Edge, Cloud	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Prometheus	An open source monitoring system with a dimensional data model, flexible query language, efficient time series database and modern alerting approach.	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Monitoring, Observability**
Helm	Helm is a tool that streamlines installing and managing Kubernetes applications	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
Thanos	Thanos is a set of components that can be composed into a highly available metric system with unlimited storage capacity, which can be added seamlessly on top of existing Prometheus deployments.	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Monitoring, Observability**
Cilium	Cilium is an open source project to provide networking, security and observability for cloud native environments such as Kubernetes clusters and other container orchestration platforms	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Security, Network, Observability**
Airflow	Open source platform for developing, scheduling, and monitoring batch-oriented workflows	Apache 2.0	Apache	Open Source	Edge, Cloud	**Orchestration, Monitoring**
Genie	CNI-Genie enables container orchestrators to seamlessly connect to the choice of CNI plugins installed on a host	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
Dask	Dask is a flexible parallel computing library for analytics.	BSD-3 Clause	Dask	Open Source	Edge, Cloud	**Data Management**

Funded by Horizon Europe Framework Programme of the European Union

Spark	Multi-language engine for executing data engineering, data science, and machine learning on single-node machines or clusters	Apache 2.0	Apache	Open Source	Edge, Cloud	**Data Management**
Docker	Docker is a platform designed to help developers build, share, and run container applications.	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
Containerd	An industry-standard container runtime with an emphasis on simplicity, robustness, and portability	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
rkt	rkt is a pod-native container engine for Linux	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
Podman	Podman is a tool for managing containers and images, volumes mounted into those containers, and pods made from groups of containers	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
CRI-O	CRI-O is an implementation of the Kubernetes CRI (Container Runtime Interface) to enable using OCI (Open Container Initiative) compatible runtimes	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Orchestration**
Scout	Open source, multi-cloud auditing tool	GPL 2.0	NCC Group	Open Source	Cloud	**Security**

Funded by Horizon Europe
Framework Programme of the European Union

Ganglia	Scalable, distributed monitoring tool for high-performance computing systems, clusters and networks	BSD-3 Clause	Planet Lab	Open Source	Cloud	**Monitoring**
Zabbix	Open source monitoring solution for network monitoring and application monitoring of millions of metrics	AGPL 3.0	CNCF	Open Source	Cloud	**Monitoring, Observability**
Nagios	Open source monitoring solution.	GPL 2.0	CNCF	Open Source	Cloud	**Monitoring**
Collectd	Small daemon which collects system information periodically and provides mechanisms to store and monitor the values in a variety of ways	MIT	collectd	Open Source	Cloud	**Monitoring**
cAdvisor	Open source monitoring and performance analysis tool specifically designed for Docker containers	Apache 2.0	Google	Open Source	Cloud	**Monitoring**
Grafana	Fully managed observability platform for applications and infrastructure	AGPL 3.0	CNCF	Open Source	Cloud	**Monitoring, Observability**
Sloth	Fast, easy and reliable Prometheus SLO generator	Apache 2.0	Sloth	Open Source	Edge, Cloud	**Observability**
Sensu	Observability pipeline that delivers monitoring as code on any cloud	MIT	CNCF	Open Source	Edge, Cloud	**Observability**
Docker Swarm	Container orchestration tool running the Docker application	Apache 2.0	CNCF	Open Source	Edge, Cloud, IoT	**Resource Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

ClearML	ClearML delivers a unified, open source platform for continuous AI	Apache 2.0	allegro.ai	Open Source	Edge, Cloud	**Artificial Intelligence**
mlflow	Open source platform for the machine learning lifecycle	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Artificial Intelligence**
Kubeflow	The Kubeflow project is dedicated to making deployments of machine learning workflows on Kubernetes simple, portable and scalable by providing a straightforward way to deploy best-of-breed open-source systems for ML to diverse infrastructures	Apache 2.0	CNCF	Open Source	Edge, Cloud	**Artificial Intelligence**
Parsl	Parsl creates parallel programs composed of Python functions and external components	Apache 2.0	Parsl	Open Source	Edge, Cloud, IoT	**Data Management**
Apache Beam	A unified programming model for Batch and Streaming data processing.	Apache 2.0	Apache Software Foundation	Open Source	Edge, Cloud, IoT	**Data Management**
River	A Python package for online/streaming machine learning.	BSD-3Clause	River	Open Source	Edge, Cloud, IoT	**Artificial Intelligence**
MXNET	Lightweight, Portable, Flexible Distributed/Mobile Deep Learning with Dynamic, Mutation-aware Dataflow Dep Scheduler; for Python, R, Julia, Scala, Go, Javascript and more	Apache 2.0	Apache Software Foundation	Open Source	Edge, Cloud, IoT	**Artificial Intelligence**

Funded by Horizon Europe Framework Programme of the European Union

Keras	Keras is an open-source library that provides a Python interface for artificial neural networks.	Apache 2.0	Keras	Open Source	Edge, Coud, IoT	**Artificial Intelligence**
dislib	dislib is a distributed computing library highly focused on machine learning on top of PyCOMPSs. Inspired by NumPy and scikit-learn, dislib provides various supervised and unsupervised learning algorithms through an easy-to-use API.	Apache 2.0	BSC	Open Source	Edge, Cloud, IoT	**Artificial Intelligence**
InfluxDB	InfluxDB enables real-time analytics by serving as a purpose-built database that optimizes processing and scaling	Apache 2.0	Influx Data	Open Source	Cloud	**Data Management**
Apache Druid	A high performance, real-time analytics database that delivers sub-second queries on streaming and batch data at scale and under load.	Apache 2.0	Apache Software Foundation	Open Source	Cloud	**Data Management**

Funded by Horizon Europe Framework Programme of the European Union

Apache IoTDB	An IoT native database with high performance for data management and analysis, deployable on the edge and the cloud. Due to its light-weight architecture, high performance and rich feature set together with its deep integration with Apache Hadoop, Spark and Flink, Apache IoTDB can meet the requirements of massive data storage, high-speed data ingestion and complex data analysis in the IoT industrial fields	Apache 2.0	Apache Software Foundation	Open Source	IoT	**Data Management**
Pegasus	A horizontally scalable, strongly consistent and high-performance key-value store	Apache 2.0	Apache Software Foundation	Open Source	Cloud	**Data Management**
Scanflow-K8s	Agent-based Framework for Autonomic Management and Supervision of ML Workflows in Kubernetes Clusters	MIT	BSC	Open Source	Edge, Cloud, IoT	**Artificial Intelligence**
Keycloak	Keycloak is an Identity and Access Management (IAM) toolkit developed in Java using the Spring framework, which manages user identity and login by using identity verification protocols such as: Open ID Connect, OAuth2, OAuth2...	Apache 2.0	CNCF	Open source	Edge, Cloud	**Security**

Funded by Horizon Europe Framework Programme of the European Union

Apache Mesos	Apache Mesos is a cluster manager that provides efficient resource isolation and sharing across distributed applications, or frameworks. It can run Hadoop, Jenkins, Spark, Aurora, and other frameworks on a dynamically shared pool of nodes.	Apache 2.0	Apache Software Foundation	Open Source	Edge, Cloud, IoT	**Resource Management**

Funded by Horizon Europe
Framework Programme of the European Union

ANNEX 3: COMMERCIAL PRODUCTS

To make the landscape as complete as possible, also commercial products have been included as they are also used by some research projects in order to provide features on top of them.

The structure of the information is as follows:

- *Product:* to easily identify the product.
- *Product description:* of the functionalities provided justifying for what the product is useful for.
- *License:* to identify the compatibilities of the licensed software with other components.
- *Owner:* the organization who owns the product.
- *OC tag level 2 and 3:* to map results with the reference architecture in order to identify gaps and challenges.

Product	Product description	License	Owner / organization	OC TAG LEVEL 2	OC TAG LEVEL 3
Nuvla	Nuvla automates the deployment of Container-as–a-Service (e.g. Kubernetes, Docker Swarm), to host the user containerised applications	Apache 2.0	SixSQ	Edge, Cloud	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Product	Product description	License	Owner / organization	OC TAG LEVEL 2	OC TAG LEVEL 3
Amazon EKS	Amazon Elastic Kubernetes Service is a Kubernetes managed service for running Kubernetes in the AWS cloud and on-premises data centres.	Apache 2.0	Amazon	Edge, Cloud	**Orchestration**
Azure AKS	AKS offers the quickest way to start developing and deploying cloud-native apps in Azure, datacenters, or at the edge with built-in code-to-cloud pipelines and guardrails	Apache 2.0	Microsoft	Edge, Cloud	**Orchestration**
Kubermatic	Open source project to centrally manage the global automation of thousands of Kubernetes clusters accross multicloud, on-prem and edge with unparalleled density and resilience.	Apache 2.0	Kubermatic	Edge, Cloud	**Orchestration**
Amazon CloudWatch	Amazon CloudWatch is a monitoring service for AWS cloud resources and the applications run on them	Proprietary	Amazon	Cloud	**Monitoring**
Microsoft Azure Monitor	Comprehensive monitoring solution for collecting, analyzing, and responding to monitoring data from your cloud and on-premises environments	Proprietary	Microsoft	Cloud	**Monitoring**

Funded by Horizon Europe Framework Programme of the European Union

Product	Product description	License	Owner / organization	OC TAG LEVEL 2	OC TAG LEVEL 3
Alibaba CloudMonitor	Service that monitors Alibaba Cloud resources and Internet applications	Proprietary	Alibaba	Cloud	**Monitoring**
RackSpace Monitoring	Set of tools that monitor, analyze and report on the availability and performance of websites, servers and other cloud resources	Proprietary	RackSpace	Cloud	**Monitoring**
VMware vCloud Suite	Enterprise-grade cloud infrastructure and management solution	Proprietary	VMware	Cloud	**Orchestration**
Azure IoT	Connects, monitors, and control devices and assets with secure cloud-to-edge solutions	Proprietary	Microsoft	IoT	**Resource Management**
AWS IoT	Connects devices to AWS Services and other devices, secures data interactions, and processes and acts upon device	Proprietary	Amazon	IoT	**Resource Management**
Datadog	Datadog is a monitoring and analytics tool for information technology (IT) and DevOps that can be used to determine performance metrics as well as event monitoring for infrastructure and cloud services	Proprietary	Datadog	Cloud	**Monitoring, Observability**
AppDynamics	Full-stack application performance management and IT operations analytics software	Proprietary	Cisco	Edge, Cloud	**Observability**

Funded by Horizon Europe Framework Programme of the European Union

Product	Product description	License	Owner / organization	OC TAG LEVEL 2	OC TAG LEVEL 3
Amazon ECS	Container orchestration service to deploy, manage, and scale containerized applications	Proprietary	Amazon	Edge, Cloud	**Orchestration**
Azure Kubernetes Service	Managed Kubernetes service with hardened security and fast delivery	Proprietary	Microsoft	Edge, Cloud	**Orchestration**
IBM Cloud Kubernetes Service	Certified, managed Kubernetes solution, for creating a cluster of compute hosts to deploy and manage containeried apps on IBM Cloud	Proprietary	IBM	Edge, Cloud	**Orchestration**
Nomad	Workload orchestrator that can deploy a mix of microservice, batch, containerized, and non-containerized applications	Proprietary	HashiCorp	Edge, Cloud	**Orchestration**
Kontena	Platform for orchestrating applications that are run on Docker containers	Proprietary	Suptask	Edge, Cloud	**Orchestration**
HPE GreenLake	HPE GreenLake provides the agility and economy of the public cloud, with the security and performance of on-premise IT	Proprietary	HPE	Edge, Cloud	**Orchestration**
AWS IoT Greengrass	Edge runtime and cloud service to build, deploy, and manage intelligent device software	Proprietary	Amazon	IoT	**Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

Product	Product description	License	Owner / organization	OC TAG LEVEL 2	OC TAG LEVEL 3
databricks	Data intelligence platform powered by generative AI	Proprietary	Databricks	Edge, Cloud	**Data Management, Artificial Intelligence**
DataRobot	Machine learning platform for automating, assuring, and accelerating predictive analysis	Proprietary	DataRobot	Cloud	**Artificial Intelligence**
Amazon SageMaker	Fully managed infrastructure, tools, and workflows to build, train, and deploy machine learning models for any use case	Proprietary	Amazon	Cloud	**Artificial Intelligence**
eXtremeDB	A high-performance, low-latency, ACID-compliant embedded database management system using an in-memory database system (IMDS) architecture and designed to be linked into C/C++ based programs.	Proprietary	McObject LLC	Cloud	**Data Management**
ObjectBox	Access your data when and where needed, with or without internet connectivity. The ObjectBox highspeed database securely stores your data privatly on-device and syncs it seamless with millions of devices and the cloud.	Apache 2.0	ObjectBox	Edge, Cloud, IoT	**Data Management**
Azure SQL Edge	Lightweight, perimeter-optimised SQL database engine with built-in artificial intelligence	MIT	Microsoft	Edge	**Data Management**

Funded by Horizon Europe Framework Programme of the European Union

Product	Product description	License	Owner / organization	OC TAG LEVEL 2	OC TAG LEVEL 3
Kibana	Run data analytics at speed and scale for observability, security, and search with Kibana. Powerful analysis on any data from any source, from threat intelligence to search analytics, logs to application monitoring	Apache 2.0	Elastic	Cloud	**Data Management**
AWS Data Pipeline	AWS Data Pipeline is a web service that can be used to automate the movement and transformation of data. With AWS Data Pipeline, data-driven workflows can be defined, so that tasks can be dependent on the successful completion of previous tasks.	MIT -0	Amazon	Cloud	**Data Management**
AWS Cloudtrail	AWS Cloudtrail helps enabling operational and risk auditing, governance, and compliance of an AWS account. Actions taken by a user, role, or an AWS service are recorded as events in CloudTrail.	Proprietary	Amazon	Cloud	**Security**
Azure Service Fabric	Azure Service Fabric is a distributed systems platform that makes it easy to package, deploy, and manage scalable and reliable microservices and containers	MIT	Microsoft	Edge, Cloud	**Resource Management, Orchestration**

Funded by Horizon Europe Framework Programme of the European Union

ANNEX 4: PROVIDED RESEARCH CHALLENGES

During the design phase of the reference architecture, it was highlighted by participants that there are still several challenges that cannot be addressed with the current state of the art of the technology. Thus, all of them were collected and listed here. An additional analysis has been performed and it is published on the website.

The table below contains only the basic information about each of the identified challenges.

Name	Building block(s)	Description
Open interfaces in the continuum to cope with modern services encapsulation agnostic to underlying heterogeneous nodes (WebAssembly)	Data management, Orchestration, Network, Monitoring & Observability	Wasm will be the primary format application in the continuum, offering seamless portability, while also supporting classic containers. Therefore, packaged modules should be deployable on any device in the continuum having a compliant runtime. Runtimes should take full advantage of the hardware, including new and emerging CPU architectures (RISC-V) and supported specialized instructions.
Security orchestration, automation and response in the continuum for cybersecurity resilience	Security	Meta-operating systems will need to include capabilities to orchestrate, automate and respond to security incidents detected in these systems. Implementing the right responses quickly minimises the time that the attacker has access to the components that constitute the continuum, thus, minimising the damage they can cause.
Strong authentication through synchronous open source web standards	Security	Keycloak is an open source identity and access management solution that has been used multiple times to secure applications by efficiently managing authentication and authorization services. Despite the security measures offered, the possibility of an attack due to human factors remains. The integration of Keycloak with FIDO2 and WebAuthn will reduce cybersecurity challenges due to phishing attacks.

Funded by Horizon Europe Framework Programme of the European Union

Enhancing interoperability in application/service and infrastructure through standardised protocols and APIs	Resource management	By establishing common protocols, it facilitates the interaction and interoperability of systems that were independently developed, enabling them to share data and functions seamlessly. This approach not only promotes compatibility across various platforms and services, but also simplifies the development and deployment processes by reducing the need for custom integration solutions.
Enforcing security and trust through zero-knowledge-based frameworks	Security, Trust	This challenge focuses on the creation and integration of a security framework founded on zero-knowledge proofs and TEEs. By leveraging these advanced cryptographic techniques, the framework aims to ensure that data transactions and computations are both secure and verifiable without exposing sensitive information.
Intelligent data management through cognitive approaches in computing continuum	Data management, Artificial intelligence	The goal of this challenge is to leverage AI and ML techniques to transform data management across the cloud-edge continuum. By integrating AI/ML algorithms with data lakes and catalog systems, it aims to create intelligent data management solutions that are dynamic, adaptive, and capable of handling large-scale, diverse data sets efficiently.
Automated and secure deployment of data spaces	Security & Privacy, Data management, Orchestration	This challenge addresses the need for technical (secure, robust, and EU regulatory compliant) infrastructure for data spaces supporting different cloud infrastructure providers for deployment of components needed for bootstrapping data spaces.
Horizontal and vertical interoperability in the continuum	Security, Trust & Reputation, Network, Artificial intelligence	This challenge faces the large set of components and technologies that all together are contributing to optimize the way cloud continuum resources are to be managed. It considers two main aspects: transparency and interoperability.

Funded by Horizon Europe Framework Programme of the European Union

Bidirectional or mutual cloud continuum to services orchestration	Resource management, Orchestration, Monitoring & Observability, Artificial intelligence	The key conceptual challenge is how resources in the cloud continuum must be managed and orchestrated, and current strategies leverage resources virtualization, clustering and slicing among others.
Native security provisioning	Security & Privacy, Trust & Reputation, Data management, Monitoring & Observability, Artificial intelligence	Cloud continuum exacerbates the security challenges. Thus, efforts should be allocated to identify a native strategy for end-to-end (vertical and horizontal) solution that while being proactive may guarantee a level of security.
Orchestration of micro-agents	Orchestration	Orchestrating efficiently micro-agents is very challenging with the current framework/approaches because they are subject to fast and hard-to-predict dynamics. Furthermore, since the state of the application is embedded within the micro-agent, data management becomes a critical performance bottleneck with data-intensive applications.
Large-Language Models in the loop for robotics	Artificial intelligence	Recent developments in the AI field offer great potential for improving robots' ability to be autonomous and to infer and reason about high-level and abstract goals, understanding which sequence of skills to apply to fulfil its role in open-world, uncertain, and highly dynamic scenarios, where some of the elements are unknown a priori and cannot be assumed to be controllable.
Mutual Attestation in dynamic groups of enclaves without TTPs	Security & Privacy	The evolving threat landscape and the necessity to execute code on machines that are beyond software developers' jurisdiction have driven them to adopt TEEs to bolster the security of their applications. One of the key challenges is the resource-intensive and time-consuming process of initializing each enclave.

Funded by Horizon Europe
Framework Programme of the European Union

Distributed computing on edge-cloud continuum for metaverse	Resource management, Orchestration, Network	The industrial metaverse promises the next evolution of industrial applications with the potential of collaboration transcending physical limitations. The computing required for achieving these capabilities would require unique architecture paradigms, new design patterns, and synchronization across participating stakeholders.
Communication and computing co-design	Resource management, Orchestration, Network	A new level of automated infrastructure is required, which takes into consideration the available computing and communication resources in a holistic manner taking into consideration the mobility of nodes and the dynamicity of application demands.
Energy-efficient ZeroCode orchestration	Orchestration	MetaOS platforms have significantly contributed into automating DevSecOps processes in a coherent manner for diverse applications and across highly diverse devices. MetaOS capabilities must expand to even greater automation and simplification of DevSecOps processes in a metaOS environment, accelerating the software development lifecycle and democratizing it to less skilled workforces.
Micro-services Secure Execution Environment	Security	The challenge is to develop a SEE for micro-services than enhances security and isolation in modern cloud environments. This involves implementing modifications to container orchestration engines to include unikernels and TEEs, improving both the isolation and migration capabilities of micro-services.
Safety & Policy Enforcement	Security & Privacy	Current AIoT systems face significant challenges in maintaining privacy, security, and ethical standards, especially when handling personalised data. Existing solutions lack robust mechanisms to enforce dynamic policies across diverse infrastructures, leading to potential compliance and security breaches.

Funded by Horizon Europe
Framework Programme of the European Union

Cybersecurity & Digital Identity Attestation	Security & Privacy	Modern digital security systems require advanced identity and access control mechanisms to protect sensitive resources. The challenge focuses on developing a robust cybersecurity framework that includes identity management, access control, and intercommunication security. This involves a comprehensive IAM system and ensuring secure intercommunication among distributed systems using message brokers.
Creation and orchestration of a highly dynamic transparent computing continuum	Resource management, Orchestration, Network, Artificial Intelligence	Despite the emergence of common interfaces for applications orchestration being key towards a real edge to cloud continuum, industry-standard approaches handle each infrastructure as a multitude of (connected) isolated silos instead of a unique virtual space. This leads to a sub-optimal fragmented view of the overall available resources, preventing the seamless deployment of fully distributed applications.
Lightweight mechanisms to build trust and secure services within the highly dynamic and transparent computing continuum	Security & Privacy, Trust & Reputation	In the computing continuum, it is important to establish security between the edge infrastructure and the edge/IoT devices. The trend to do so is to design ZTAs. Zero Trust paradigm starts from the premise that trust is never granted implicitly but must be continually evaluated. Resources must be restricted to those with a need to access and grant only the minimum privileges needed to perform the mission.

Funded by Horizon Europe Framework Programme of the European Union

ANNEX 5: PROJECTS PARTICIPATING IN THE ARCHITECTURE DEFINITION

Topic	Project	Description (TAGS)
NGIoT	TERMINET	Reference architecture to showcase the interconnection and security of IoT-enabled edge computing islands, composed of heterogeneous IoT devices and enhanced with distributed AI and Federated learning capabilities, through and end-to-end SDN fabric. (*IoT, edge, network, artificial intelligence, data management, orchestration, blockchain*)
	ASSIST-IoT	Reference architecture in which intelligence can be distributed among nodes by implementing artificial intelligence and machine learning close to data generation and actuation, and hyperconnecting nodes, in the edge-cloud continuum, over softwarised smart networks. (*IoT, edge, artificial intelligence*)
	VEDLIoT	IoT platform that uses deep learning algorithms distributed throughout the IoT continuum. (*IoT, data management, artificial intelligence*)
Cloud	CHARITY	Framework that takes advantage of novel cloud architecture, a computing and network continuum autonomous orchestration, to overcome the challenges as well as meet the requirements of media applications. (*Cloud, network, orchestration*)
	PHYSICS	Cutting-edge, scalable and cost-effective FaaS application workflows optimally placed and operated across multiple locations, edge computing nodes and multi-cloud resources. (*Cloud, edge, FaaS, orchestration, application workflows, low code, resource management optimisation*)

Funded by Horizon Europe Framework Programme of the European Union

	SERRANO	Novel ecosystem of cloud-based technologies, ranging from specialised hardware resources to software toolsets. (*Cloud, edge, security, orchestration, artificial intelligence*)
Software	PIACERE	Tools, techniques and methods to allow organisations to develop and operate IaC through DevSecOps practices as they would do with traditional code. (Cloud, network)
Meta-OS	aerOS	Meta operating system that follows a collaborative IoT-edge-cloud architecture supporting flexible deployments to achieve an optimal solution while satisfying the given constraints. (*IoT, edge, cloud, orchestration, network, artificial intelligence, trust, security, data management*)
	FLUIDOS	Fluid, dynamic, scalable and trustable computing continuum that spans across devices, unifies edge and cloud in an energy-aware fashion, and possibly extends beyond administrative boundaries. (*Cloud, edge, artificial intelligence, security, resource management*)
	ICOS	Meta operating system for a continuum, addressing challenges of devices volatility and heterogeneity, service execution and performance, trust, security and privacy, and costs reduction. (*Cloud, edge, resource management, orchestration, data management, artificial intelligence, security, trust*)
	NEMO	Open source, flexible, adaptable, cybersecure and multi-technology meta-Operating System. (*Edge, cloud, orchestration, artificial intelligence, security*)
	NEBULOUS	Meta Operating System and platform for enabling transient fog brokerage ecosystems that seamlessly exploit edge and fog nodes, in conjunction with multi-cloud resources, to cope with the requirements posed by low latency applications. (*Cloud, edge, data management, artificial intelligence, security, blockchain, monitoring*)

Funded by Horizon Europe
Framework Programme of the European Union

	NEPHELE	Efficient, reliable and secure end-to-end orchestration of hyper-distributed applications over programmable infrastructure that is spanning across the compute continuum from Cloud-to-edge-to-IoT, removing existing openness and interoperability barriers in the convergence of IoT technologies against cloud and edge computing orchestration platforms, and introducing automation and decentralized intelligence mechanisms powered by 5G and distributed AI technologies. (*Cloud, edge, IoT, network, artificial intelligence, orchestration*)
Open Source	VITAMIN-V	RISC-V open-source software stack for cloud services with iso-performance to the cloud-dominant x86 counterpart and a powerful virtual execution environment for software development, validation, verification, and test that considers the relevant RISC-V ISA extensions for cloud deployment. (*Cloud, artificial intelligence, data management*)
	AERO	Open-source software ecosystem that encompasses a wide range of software components ranging from operating systems to compilers, runtimes, system software and auxiliary software deployment services for cloud computing. (*Cloud, security*)
	OPENCUBE	Full-stack solution of a validated European Cloud computing blueprint to be deployed on European hardware infrastructure. (*Cloud*)
Cognitive cloud	SovereignEdge.COGNIT	Distributed FaaS paradigm for edge application management and smart orchestration, which will change how applications and services are deployed and executed in the cloud-edge continuum. (*Cloud, edge, artificial intelligence*)
	CODECO	Cognitive, cross-layer and highly adaptive Edge-Cloud management framework with a unique orchestration approach that provides support for data management and governance decentralised data

		workflow; dynamic offloading of computation and computation status; and adaptive networking services. (*Cloud, edge, artificial intelligence, data management, orchestration, network*)
	EDGELESS	Orchestration system that provides a flexible horizontally scalable compute solution able to fully use heterogeneous edge resources, while preserving vertical integration with the cloud and the benefits of serverless. (*Cloud, artificial intelligence, orchestration, edge, network*)
	MLSYSOPS	Framework for autonomic end-to-end system management across the full cloud-edge continuum. (*Cloud, edge, resource management, orchestration, artificial intelligence, security*)
	AC3	Agile and cognitive cloud-edge continuum management framework providing scalability, agility, effectiveness, and dynamicity in service delivery over the cloud edge computing continuum infrastructure. (*Cloud, edge, data management, IoT, artificial intelligence*)
	ACES	Infused autopoiesis and cognition on different levels of cloud management to empower with AI different functionalities. (*Cloud, artificial intelligence, edge, resource management, monitoring, orchestration*)
	COGNIFOG	Cognitive Fog Framework to reduce energy consumption and latency, reduce OPEX and ensure European leadership. (*Cloud, edge, artificial intelligence, security, orchestration*)
Swarm	OASEES	Open, decentralized, intelligent, programmable edge framework for Swarm architectures and applications, leveraging the Decentralized Autonomous Organization paradigm and integrating Human-in-the-Loop processes for efficient decision making. (*Edge, data management, artificial intelligence*)
	TARDIS	Novel programming paradigm with a toolbox for supporting the development and execution of applications. (*Data management, artificial intelligence*)

Funded by Horizon Europe Framework Programme of the European Union

	INCODE	Open platform for the deployment and dynamic management of end user applications, over distributed, heterogeneous and trusted IoT-Edge node infrastructures, with enhanced programmability features and tools at both the network infrastructure level and the service design and operational level. (*Cloud, edge, IoT, network, orchestration*)
	SMARTEDGE	Cross-layer toolchain that facilitates the seamless and real-time discoverability and composability of autonomous intelligence swarm. (*Cloud, edge, network, orchestration*)
Cognitive Continuum	INTEND	Cutting edge artificial intelligence solutions to enable the novel intent-based data operation on the cognitive computing continuum. (*Cloud, edge, IoT, artificial intelligence)*
Others	TRUSTEE	Green, secure, trustworthy and privacy-aware framework that aggregates multiple interdisciplinary data repositories and also takes into account other European data federation spaces and transnational initiatives. (*Data management, security, trust*)
	CROSSCON	Open, flexible, highly portable and vendor-independent IoT security stack that can run across different edge devices and multiple hardware platforms. (*Security, edge, IoT*)

Funded by Horizon Europe
Framework Programme of the European Union