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Open Continuum

# D4.3 Towards a European Ecosystem for the Computing Continuum

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| | |
|---|---|
| Abstract | The aim of this deliverable is to collect the views of the different Horizon and H2020 projects contributing to the realisation of a European computing continuum. The different views will be harmonised and synthesized in a number of concrete actions to be pursued through the collaboration among active projects. |
| Keywords | Ecosystem, Building blocks, Interoperability, Standardisation |

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


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# EXECUTIVE SUMMARY

This deliverable is guiding the continuum project portfolio toward a common strategy for supporting the establishment of an open European ecosystem for the cloud-edge-IoT continuum

1) it provides a background and a rational for integration need in a future continuum computing ecosystem,
2) it provides a definition of terms, making a separation between terms that are defined at standardisation level and others,
3) it provides a landscape of projects, covering support actions, Meta-Operating Systems (DATA-01-05) projects, Cognitive Cloud projects (DATA-01-02), Swarm Computing projects (DATA-01-03), Open Source for Cloud Services projects (DIGITAL-EMERGING-01-26), and a number of other projects, focusing on the value to -computing continuum,
4) it suggests a strategic approach integrating a taxonomy of reference building blocks and associated enablers. And
5) it concludes with an approach to engage projects into the definition of building blocks and enablers.



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# ABBREVIATIONS

| | |
|---|---|
| **AIOTI** | Alliance for IoT and Edge Computing Innovation |
| **BDVA** | Big Data Value Association |
| **CC** | Cloud Computing |
| **CEI** | Cloud, Edge and IoT |
| **EC** | European Commission |
| **ECC** | European Cloud Computing |
| **EPI** | European Processor Initiative |
| **MetaOS** | Meta Operating System |
| **OSD** | Open Source Development |
| **IEC** | International Electrotechnical Commission |
| **IEEE SA** | Institute of Electrical and Electronics Engineers Standards Association |
| **IoT** | Internet of things |
| **ISO** | International Organisation for Standardisation |
| **ITU-T** | ITU Telecommunication Standardization Sector (ITU-T) |
| **MEC** | Multi-access Edge Computing |
| **RA** | Reference Architecture |
| **SDO** | Standard Development Organisation |



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# 1 Introduction

## 1.1 Purpose

The aim of this document is to collect the views of the different Horizon Europe and H2020 projects contributing to the realisation of a European computing continuum. The different views will be harmonised and synthesized in a number of concrete actions to be pursued through the collaboration among active projects.

## 1.2 Background

On 11 November 2021, the European Commission organized an event titled "Digital Autonomy in the Computing Continuum"[1]. The meeting gathered experts with different academic and industrial backgrounds. They discussed the current and future trends of Cloud and IoT domains and emphasized the importance of the Data Economy and its impact on the global economy as a whole[2]. European Commission's (EC) goal is to allow European companies to regain leadership in the Data Economy and act independently if needed. However, EC emphasized that this is not an isolationist trend; the intention to participate in the global digital community is clear. The participants recognized that the Cloud and IoT domains are converging and will form a Computing Continuum. And they expect a fivefold data volume increase with 80 percent being processed in distributed systems which will have a significant impact on data-driven businesses. The program was centered around the following topics: Cognitive Cloud, Open Source for Digital Autonomy, and Decentralized Intelligence and Swarm Computing, and the EC gathered feedback from the audience as part of the process of forming its vision for the coming few years.

The EC strategy and policy concerning the digital decade [1] states targets and objectives in terms of skills, government, infrastructure and business, including

- Tech up-take objective for digital transformation: 75% of EU companies using Cloud/AI/Big data
- Data – Edge and cloud objective for secure and sustainable digital infrastructure: 10 000 climate-neutral highly secure edge nodes.

[1] https://digital-strategy.ec.europa.eu/en/library/digital-autonomy-computing-continuum

[2]https://www.h-cloud.eu/news/highlights-of-the-ec-workshop-digital-autonomy-in-the-computing-continuum/



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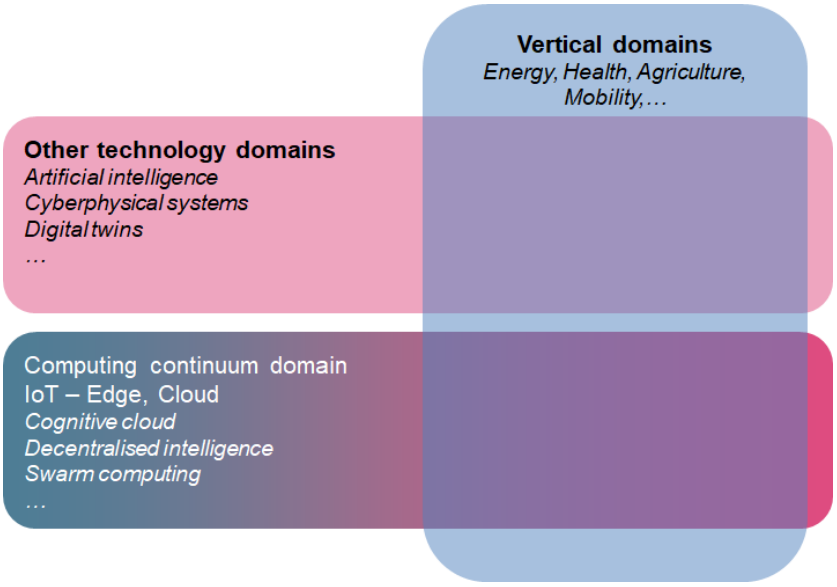


*Figure 1 – Positioning of the computing continuum domain*

## 1.3 Integration Needs in an Ecosystem

Figure 1 describes the resulting integration needs in an Ecosystem:

- The lower horizontal layer focuses on the computing continuum technical domain. It shows the need to integrate IoT, edge and cloud technology, in particular topics such as the cognitive cloud, decentralised intelligence, or swarm computing[3].
- The upper horizontal layer addresses other technology domains that will rely on the computing continuum, such as artificial intelligence, cyber physical system or digital twins.
- Finally, the vertical layer focuses on the support of application domains, such as energy, health, agriculture or mobility.

In order for Europe to play a leading role in the computing continuum it has to influence and possibly lead this integration in the ecosystem.

## 1.4 Structure of this Document

This document has the following structure:

- Section 2 provides a list of definitions that are important for the computing continuum domain.
- Section 3 provides a first list of projects of interest with an analysis of their value for the computing continuum domain.
- Section 4 provides an initial characterization of the computing continuum ecosystem.
- Section 5 proposed a strategy for creating and impact and suggest work to be carried out.

[3] The AIOTI standardisation working group provide important sources of information on the topic. See https://aioti.eu/resources/standardisation-resources/



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# 2 Definitions Used in Computing Continuum Ecosystems

The purpose of this section is to list the common terms that will be used in the computing continuum ecosystems. We have chosen

- existing terms that have a definition agreed in standards, as they reflect a stronger consensus,
- other terms that do not yet have been agreed in standards, which may indicate the need for fill some gaps.

## 2.1 Existing Terms Agreed in Standards

*Table 1 – Terms agreed in standards*

| | |
|---|---|
| General terms | |
| Ecosystem | Infrastructure and services based on a network of organizations and stakeholders<br>Note 1 to entry: Organizations can include public bodies.<br>*ISO/IEC TS 27570:2021 Privacy protection — Privacy guidelines for smart cities*<br>*ISO/IEC 27400:2022 Cybersecurity — IoT security and privacy — Guidelines* |
| Stakeholder | Role, position, individual, organization, or classes thereof, having an interest, right, share, or claim, in an entity of interest<br>EXAMPLE: End users, operators, acquirers, owners, suppliers, architects, developers, builders, maintainers, regulators, taxpayers, certifying agencies, and markets.<br>*ISO/IEC/IEEE 42010:2022 Software, systems and enterprise — Architecture description* |
| Trustworthiness | Ability to meet stakeholders' expectations in a verifiable way<br>Note 1 to entry: Depending on the context or sector, and also on the specific product or service, data, technology and process used, different characteristics apply and need verification to ensure stakeholders' expectations are met.<br>Note 2 to entry: Characteristics of trustworthiness include, for instance, accountability, accuracy, authenticity, availability, controllability, integrity, privacy, quality, reliability, resilience, robustness, safety, security, transparency and usability.<br>Note 3 to entry: Trustworthiness is an attribute that can be applied to services, products, technology, data and information as well as to organizations.<br>Note 4 to entry: Verifiability includes measurability and demonstrability by means of objective evidence. |
| Cloud computing terms | |
| Cloud computing | Paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand.<br>NOTE – Examples of resources include servers, operating systems, networks, software, applications, and storage equipment.<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |



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| | |
|---|---|
| Cloud capabilities type | Classification of the functionality provided by a cloud service to the cloud service customer, based on resources used.<br>NOTE – The cloud capabilities types are application capabilities type, infrastructure capabilities type and platform capabilities type.<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Cloud service | One or more capabilities offered via cloud computing invoked using a defined interface.<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Tenant | One or more cloud service users sharing access to a set of physical and virtual resources.<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Cloud service-oriented architecture | |
| Composition | Result of assembling a collection of elements for a particular purpose<br>*ISO/IEC 18384-1:2016 Information technology — Reference Architecture for Service Oriented Architecture (SOA RA) — Part 1: Terminology and concepts for SOA* |
| Orchestration | Type of composition where one particular element is used by the composition to oversee and direct the other elements<br>Note 1 to entry: The element that directs an orchestration is not part of the orchestration (Composition instance) itself.<br>*ISO/IEC 18384-1:2016 Information technology — Reference Architecture for Service Oriented Architecture (SOA RA) — Part 1: Terminology and concepts for SOA* |
| Collaboration | Type of composition whose elements interact in a non-directed fashion, each according to their own plans and purposes without a predefined pattern of behaviour<br>*ISO/IEC 18384-1:2016 Information technology — Reference Architecture for Service Oriented Architecture (SOA RA) — Part 1: Terminology and concepts for SOA* |
| Choreography | Type of composition whose elements interact in a non-directed fashion with each autonomous part knowing and following an observable predefined pattern of behaviour for the entire (global) composition<br>Note: Choreography does not require complete or perfect knowledge of the pattern of behaviour.<br>*ISO/IEC 18384-1:2016 Information technology — Reference Architecture for Service Oriented Architecture (SOA RA) — Part 1: Terminology and concepts for SOA* |
| Cloud service capability | |
| Communications as a Service (CaaS) | Cloud service category in which the capability provided to the cloud service customer is real time interaction and collaboration.<br>NOTE CaaS can provide both application capabilities type and platform capabilities type.<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Compute as a Service (CompaaS) | Cloud service category in which the capabilities provided to the cloud service customer are the provision and use of processing resources needed to deploy and run software. |



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| | |
|---|---|
| | NOTE To run some software, capabilities other than processing resources may be needed.<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Data Storage as a Service (DSaaS) | Cloud service category in which the capability provided to the cloud service customer is the provision and use of data storage and related capabilities.<br>NOTE DSaaS can provide any of the three cloud capabilities types.<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Infrastructure as a Service (IaaS) | Cloud service category in which the cloud capabilities type provided to the cloud service customer is an infrastructure capabilities type<br>NOTE The cloud service customer does not manage or control the underlying physical and virtual resources, but does have control over operating systems, storage, and deployed applications that use the physical and virtual resources. The cloud service customer (may also have limited ability to control certain networking components (e.g., host firewalls).<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Platform as a Service (PaaS) | Cloud service category in which the cloud capabilities type provided to the cloud service customer is a platform capabilities type<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Software as a Service (SaaS) | Cloud service category in which the cloud capabilities type provided to the cloud service customer is an application capabilities type (3.2.1).<br>*ISO/IEC 17788:2014 Information technology — Cloud computing — Overview and vocabulary* |
| Edge computing terms | |
| Edge | Boundary between pertinent digital and physical entities, delineated by networked sensors and actuators<br>Note: Pertinent digital entities means that the digital entities which need to be considered can vary depending on the system under consideration and the context in which those entities are used.<br>*ISO/IEC TR 23188:2020 Information technology — Cloud computing — Edge computing landscape* |
| Edge computing | Distributed computing in which processing and storage takes place at or near the edge, where the nearness is defined by the system's requirements<br>*ISO/IEC TR 23188:2020 Information technology — Cloud computing — Edge computing landscape* |
| Edge computing system | System that uses the structure and capabilities of edge computing<br>*ISO/IEC TR 30164:2020 Internet of things (IoT) — Edge computing* |
| Edge computing entity | Thing (physical or non-physical) having a distinct existence in an edge computing system, with connection, storage and computation capabilities<br>*ISO/IEC TR 30164:2020 Internet of things (IoT) — Edge computing* |
| IoT and cyberphysical systems | |



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| | |
|---|---|
| IoT system | Infrastructure of interconnected entities, people, systems and information resources together with services which processes and reacts to information from the physical world and virtual world<br>*ISO/IEC 20924:2021 Information technology — Internet of Things (IoT) — Vocabulary* |
| IoT device | Entity of an IoT system that interacts and communicates with the physical world through sensing or actuating<br>Note: An IoT device can be a sensor or an actuator<br>*ISO/IEC 20924:2021 Information technology — Internet of Things (IoT) — Vocabulary* |
| Actuator | IoT device that changes one or more properties of a physical entity in response to a valid input<br>*ISO/IEC 20924:2021 Information technology — Internet of Things (IoT) — Vocabulary* |
| Sensor | IoT device that measures one or more properties of one or more physical entities and outputs digital data that can be transmitted over a network<br>*ISO/IEC 20924:2021 Information technology — Internet of Things (IoT) — Vocabulary* |
| Operational technology (OT) | Hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices and systems, processes and events in the organization<br>*ISO/IEC 20924:2021 Information technology — Internet of Things (IoT) — Vocabulary* |

## 2.2 Other Terms

As the ecosystem is shaping up, there will be a need to agree on a further list of terms. They have not been agreed yet at standardisation level.

*Table 2 – Other terms*

| Computing continuum | |
|---|---|
| Cloud computing elasticity | Degree to which a system is able to adapt to workload changes by provisioning and de-provisioning resources in an autonomic manner, such that at each point in time the available resources match the current demand as closely as possible<br>*https://en.wikipedia.org/wiki/Elasticity_%28cloud_computing%29* |
| Cognitive computing | Technology platforms influenced by cognitive science to simulate the human thought process and encompass artificial intelligence and signal processing. This may include capabilities like machine learning, reasoning, natural language processing (NLP), speech and vision recognition, human-computer interaction (HCI) and more.<br>*https://www.cognizant.com/us/en/glossary/cognitive-computing#list-C* |
| Far edge | Edge computing infrastructure which is deployed in a location farthest from the cloud data centre(s) and closest to the users<br>*https://tech.ginkos.in/2019/06/far-edge-vs-near-edge-in-edge-computing.html* |
| Near edge | Edge computing infrastructure which is deployed in a location between the far edge and the cloud data centre<br>*https://tech.ginkos.in/2019/06/far-edge-vs-near-edge-in-edge-computing.html* |



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| | |
|---|---|
| Swarm computing | Swarm computing is a way of leveraging the spare compute and storage functions on devices such as smart phones and tablets to perform typically hosted server functions<br>*https://www.linkedin.com/pulse/swarm-computing-what-why-you-should-care-scott-draffin/?trk=public_post* |
| Swarm intelligence | Collective behaviour of decentralized, self-organized systems, natural or artificial.<br>*https://en.wikipedia.org/wiki/Swarm_intelligence* |



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# 3 Landscape of projects

This section provides a first landscape of projects that can be involved directly or indirectly to the computing continuum ecosystem.

## 3.1 Support actions

Several support actions funded by the EC are important as they can have direct on the creation of synergistic actions. The table below will be updated to include:

- other support actions of interest;
- additional objectives of support actions related to the computing continuum; and
- additional objectives of support actions related to open source for digital autonomy.

*Table 3 – Support actions Create-IoT and U4IoT*

| | | |
|---|---|---|
| Create-IoT and U4IoT | Dates and URL (Create-IoT) | 1/1/2017 – 30/6/2020<br>*https://cordis.europa.eu/project/id/732929* |
| | Dates and URL (U4IoT) | 1/1/2017 – 31/12/2019<br>*https://cordis.europa.eu/project/id/732078* |
| | Type of support | Synergy between large-scale pilots |
| | Supported projects | Activage, Autopilot, IoF2020, Monica, Synchronicity |
| | Result | • Architecture commonalities<br>• Interoperability commonalities<br>• Security, privacy and trust commonalities |

*Table 4 – Support action OpenDei*

| | | |
|---|---|---|
| OpenDei | Dates and URL | 1/6/2019 – 31/12/2022<br>*https://www.opendei.eu/*<br>*https://cordis.europa.eu/project/id/857065* |
| | Type of support | Digital transformation of European industry<br>Focus on data spaces and digital platforms<br>Focus on 4 domains: energy, smart manufacturing, agrifood and health |
| | Supported projects | Smart manufacturing: Qu4lity, ZDMP, European factory platform, ConnectedFactories, Kyklos 4.0, DigiPrime, Shop4CF<br>Agrifood: Demeter, Atlas, agROBOfood, IoT, SmartAgriHubs, Auroral, dRural<br>Energy: Platone, Interconnect, Platoon, Interrface, synergy, coordiNet, BDOPEM, OneNET<br>Health: InteropEHRate, Smart4Health, Activage, Pharaon, SmartBear, GateKeeper, Shapes, Adlife, Faith, AICCELERATE, AIDPATH, HoSMARTAI, Tendo, ICUCovidn |



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| | | |
|---|---|---|
| | Results | • Data space design principles<br>• Vision for architecture and interoperability convergence |

*Table 5 – Support actions NGIoT, EU-IoT*

| | | |
|---|---|---|
| NGIoT and EU-IoT | Dates and URL (NGIoT) | 1/11/2018 – 31/10/2021<br>*https://www.ngiot.eu/*<br>*https://cordis.europa.eu/project/id/825082* |
| | Dates and URL (EU-IoT) | https://cordis.europa.eu/project/id/956671<br>1/10/2020 – 31/03/2023 |
| | Type of support | IoT with EU values. Strategy for an open and inclusive ecosystem |
| | Supported projects | ICT 56 - H2020: IntellIoT, VEDLIoT, Terminet, IoT-NGIN, InGenious, Assist-IoT<br>European security and privacy: Chariot, Brain-IoT, Enact, IoT-Crawler, SecureIoT, Semiotics, SerioT, Sofie |
| | Results | • Knowledge areas: Data spaces, infrastructure (near edge, far edge), Human/IoT interface<br>• Enablers: Edge Computing; 5G, Artificial Intelligence and analytics, Augmented Reality and Tactile Internet, Digital Twin, Distributed Ledgers<br>• End-user engagement |

*Table 6 – Support actions Hub4Cloud, H-Cloud*

| | | |
|---|---|---|
| Cloud support actions Hub4Cloud and H-Cloud | Dates and URL (Hub4Cloud) | 1/1/2021 – 30/09/2022<br>*https://www.h-cloud.eu/*<br>*https://cordis.europa.eu/project/id/101016673* |
| | Dates and URL (H-Cloud URL) | 1/1/2020 – 31/03/2022<br>*https://www.h-cloud.eu/*<br>*https://cordis.europa.eu/project/id/871920* |
| | Type of support | Cloud projects |
| | Supported projects | H-Cloud |
| | Result | • Workshop on the computing continuum<br>*https://www.h-cloud.eu/news/highlights-of-the-ec-workshop-digital-autonomy-in-the-computing-continuum/*<br>• Workshop on the computing continuum<br>*https://www.h-cloud.eu/news/highlights-of-the-ec-workshop-digital-autonomy-in-the-computing-continuum/* |

*Table 7 – Support actions for the continuum (OpenContinuum, UnlockCEI)*

| | | |
|---|---|---|
| European Cloud Edge & IoT | Dates and URL (Open Continuum) | 1/9/2022 – 31/08/2024<br>*https://eucloudedgeiot.eu/*<br>*https://cordis.europa.eu/project/id/101070030* |



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| | | |
|---|---|---|
| Continuum | Dates and URL (UnlockCEI) | 1/6/2022 – 30/11/2024<br>*https://eucloudedgeiot.eu/*<br>*https://cordis.europa.eu/project/id/101070571* |
| | Type of support | Building the European Cloud, Edge & IoT Continuum for business and research |
| | Supported projects | MetaOS: aerOS, FLUIDOS, ICOS, Nebulous, Nemo, Nephele |
| | Result | Projects just started |

## 3.2 Research Projects to Support

This section lists the research projects that may contribution to the computing continuum ecosystem. It will be updated during the project. The tables below will be updated to include:

- other projects of interest;
- additional project objectives related to the computing continuum; and
- additional project objectives related to open source for digital autonomy.

*Table 8 – Research projects to support*

| | |
|---|---|
| Cloud Computing: towards a smart cloud computing continuum | *https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/ict-40-2020* |
| Cognitive Cloud<br>CL4-2022-DATA-01-02 | Adoption and exploitation of Artificial Intelligence techniques to advance automation and dynamic Adaptation of resource management in Cloud and Edge systems<br>*https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl4-2022-data-01-02* |
| Open source for cloud-based services<br>CL4-2022-DIGITAL-EMERGING-01-26 | Open-source enablers for Digital Autonomy<br>*https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl4-2022-digital-emerging-01-26* |
| Programming tools for decentralised intelligence and swarms<br>CL4-2022-DATA-01-03 | Architectures, programming environments, and tools for distributed multi-device swarms and decentralised intelligence across the Computing Continuum<br>*https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl4-2022-data-01-03* |
| Future European platforms for the Edge: Meta Operating Systems<br>CL4-2021-DATA-01-05 | Next generation of higher-level (meta) operating systems for the continuum<br>Trust through open standards and - where applicable - open source.<br>*https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl4-2021-data-01-05* |

## 3.3 MetaOS Projects



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This section lists the research projects funded by CL4-2021-DATA-01-05 (Future European platforms for the Edge: Meta Operating Systems (RIA))

### 3.3.1 aerOS

*Table 9 – MetaOS project: Aeros*

| | | |
|---|---|---|
| aerOS | Dates and URL | 01/09/2022 – 31/08/2025<br>*https://cordis.europa.eu/project/id/101069732*<br>*https://aeros-project.eu/* |
| | Contact point | Carlos Palau cpalau@dcom.upv.es<br>Harilaos Koumaras koumaras@iit.demokritos.gr (Technical manager) |
| | Title | Autonomous, scalablE, tRustworthy, intelligent European meta Operating System for the IoT edge-cloud continuum |
| | Objectives | The project aerOS aims at transparently utilising the resources on the edge-to-cloud computing continuum for enabling applications in an effective manner, incorporating multiple services deployed on such a path. Therefore, aerOS will establish the missing piece: a **common meta operating system** that follows a collaborative IoT-edge–cloud **architecture supporting flexible deployments (e.g. federated or hierarchical**), bringing tremendous benefits as it enables the **distribution of intelligence and computation** – including Artificial Intelligence (AI), Machine Learning (ML), and big data analytics – to achieve an optimal solution while satisfying the given constraints.<br>The overarching goal of aerOS is to design and build a **virtualized, platform-agnostic** meta operating system for the IoT edge-cloud continuum. As a solution, to be executed on any Infrastructure Element within the IoT edge-cloud continuum – hence, independent from underlying hardware and operating system(s) – aerOS will:<br>• deliver common virtualized services to enable orchestration, virtual communication (network-related programmable functions), and efficient support for frugal, explainable AI and creation of distributed data-driven applications;<br>• expose an API to be available anywhere and anytime (location-time independent), flexible, resilient and platform-agnostic; and<br>• include a set of infrastructural services and features addressing cybersecurity, trustworthiness and manageability.<br>aerOS will:<br>• use context-awareness to distribute software task (application) execution requests;<br>• support intelligence as close to the events as possible;<br>• support execution of services using “abstract resources” (e.g., virtual machines, containers) connected through a smart network infrastructure;<br>• allocate and orchestrate abstract resources, responsible for executing service chain(s) and<br>• support for scalable data autonomy. |



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| | First analysis | Capabilities:<br>• context-aware distributed execution<br>• intelligence close to event<br>• services on the continuum<br>• orchestration of resources over continuum<br>• scalable data autonomy? |

### 3.3.2 FLUIDOS

*Table 10 – MetaOS project: Fluidos*

| | | |
|---|---|---|
| FLUIDOS | Dates and URL | 01/09/2022 – 31/08/2025<br>*https://cordis.europa.eu/project/id/101070473*<br>*https://www.fluidos.eu/* |
| | Contact point | Albert Seubers albert.seubers@martel-innovate.com<br>Fulvio Risso fulvio.risso@polito.it (Technical manager)<br>*MARTEL is the coordinator* |
| | Title | Flexible, scaLable and secUre decentralIzeD Operating System |
| | Objectives | FLUIDOS leverages the enormous, unused processing capacity at the edge, scattered across heterogeneous edge devices that struggle to integrate with each other and to coherently form a seamless computing continuum. By way of a disruptive, open-source paradigm that hinges upon secure protocols for advertisement and discovery, AI-powered resource orchestration and intent-based service integration, FLUIDOS will create a 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. Notwithstanding its innovation signature, FLUIDOS will build upon consolidated Operating Systems and orchestration solutions like Kubernetes, on top of which it will provide.<br>• A new, enriched layer enacting resource sharing through advertisement/agreement procedures (in the horizontal dimension), and<br>• Hierarchical aggregation of nodes, inspired by Inter-domain routing in the Internet (in the vertical dimension).<br>• Intent-based orchestration will leverage advanced AI Algorithms to optimize costs and energy usage in the continuum, promoting efficient usage of edge resources.<br>• A Zero-Trust paradigm will allow FLUIDOS to securely control and access geographically diverse resources, while Trusted Platform Modules will provide strong isolation and guarantee a safe deployment of applications and services.<br>FLUIDOS will pursue the above goals through the creation of an open, collaborative ecosystem, focused on the development of a multi-stakeholder market of edge services and applications, promoting European digital autonomy. The involvement of stakeholders is planned from the outset of the project through pilots and demonstrator in the fields of intelligent energy, agriculture and logistics, which will challenge FLUIDOS capabilities to adapt to |



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| | | different environments and operating conditions, while showcasing its ground-breaking innovation potential. |
| | First analysis | Capabilities:<br>• Resource sharing through agreement procedures<br>• Hierarchical aggregation of nodes, inspired by inter-domain routing<br>• Intent-based orchestration, using AI algorithms for efficient usage of edge resources<br>• Zero-trust paradigm |

### 3.3.3 ICOS

*Table 11 – MetaOS project: ICOS*

| | | |
|---|---|---|
| ICOS | Dates and URL | 01/09/2022 – 31/08/2025<br>*https://cordis.europa.eu/project/id/101070177*<br>*https://www.icos-project.eu/* |
| | Contact point | Francesco D'Andria francesco.dandria@atos.net<br>*Xavier Masip xavier.masip@upc.edu (Technical manager) ATOS is the coordinator* |
| | Title | Towards a functional continuum operating system |
| | Objectives | The unstoppable proliferation of novel computing and sensing device technologies, and the ever-growing demand for data-intensive applications in the edge and cloud, are driving a paradigm shift in computing around dynamic, intelligent and yet seamless interconnection of IoT, edge and cloud resources, in one single computing system to form a continuum. Many research initiatives have focused on deploying a sort of management plane intended to properly manage the continuum. Simultaneously, several solutions exist aimed at managing edge and cloud systems through not suitably addressing the whole continuum challenges though. The next step is, with no doubt, the **design of an extended, open, secure, trustable, adaptable, technology** agnostic and much more complete management strategy, covering the full continuum, i.e. IoT-to-edge-to-cloud, with a clear focus on the network connecting the whole stack, leveraging off-the-shell technologies (e.g. AI, data, etc.), but also open to accommodate novel services as technology progress goes on. The ICOS project aims at covering the set of challenges coming up when addressing this continuum paradigm, proposing an approach embedding a well-defined set of functionalities, ending up in the definition of an IoT2cloud Operating System (ICOS). Indeed, the main objective of the project ICOS is to design, develop and validate a meta operating system for a continuum, by addressing the challenges of:<br>• devices volatility and heterogeneity, continuum infrastructure virtualization and diverse network connectivity;<br>• optimized and scalable service execution and performance, as well as resources consumptions, including power consumption;<br>• guaranteed trust, security and privacy, and;<br>• reduction of integration costs and effective mitigation of cloud provider lock-in effects, in a data-driven system built upon the principles of |


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| | | openness, adaptability, data sharing and a future edge market scenario for services and data. |
| | First analysis | Capabilities:<br>• continuum dynamic reconfiguration (devices volatility and heterogeneity)<br>• continuum virtualisation<br>• continuum connectivity<br>• energy efficient scalable service execution and performance<br>• security privacy and trust<br>• integration of data ecosystems |

### 3.3.4 Nebulous

*Table 12 – MetaOS project: Nebulous*

| | | |
|---|---|---|
| Nebulous | Dates and URL | 01/09/2022 – 31/08/2025<br>*https://cordis.europa.eu/project/id/101070516*<br>*https://www.nebulouscloud.eu/* |
| | Contact point | Lluis Echeverria lluis.echeverria@eurecat.org |
| | Title | A meta operating system for brokering hyper-distributed applications on Cloud computing continuums |
| | Objectives | NebulOus will accomplish substantial research contributions in the realms of cloud and fog computing brokerage by introducing advanced methods and tools for enabling secure and optimal application provisioning and reconfiguration over the cloud computing continuum. NebulOus will develop a novel 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. The envisaged solution includes the following main directions of work:<br>• Development of appropriate modelling methods and tools for describing the cloud computing continuum, application requirements, and data streams; these methods and tools will be used for assuring the QoS of the provisioned brokered services.<br>• Efficient comparison of available offerings, using appropriate multi-criteria decision-making methods that are able to consider all dimensions of consumer requirements.<br>• Intelligent applications, workflows and data streams management in the cloud computing continuum.<br>• Addressing in a unified manner the security aspects emerging in of transient cloud computing continuums (e.g., access control, secure network overlay etc.).<br>• Conducting and monitoring smart contracts-based service level agreements. |
| | First analysis | Capabilities<br>• Models and tools supporting the continuum<br>• Multi-criteria methods for metaOS decision making<br>• Security network overlay |



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|---|---|---|
| | | • Management of smart contract SLA |

### 3.3.5 Nemo

*Table 13 – MetaOS project: Nemo*

| | | |
|---|---|---|
| Nemo | Dates and URL | 01/09/2022 – 31/08/2025<br>*https://cordis.europa.eu/project/id/101070118*<br>*https://meta-os.eu/* |
| | Contact point | Enric Pere Pages Montanera enric.pages@atos.net<br>*Harry Skianis cskianis@synelixis.com (Technical manager )ATOS is the coordinator and ECLIPSE is participating* |
| | Title | Next Generation Meta Operating System |
| | Objectives | NEMO aims to establish itself as the game changer of IoT-Edge-Cloud Continuum by introducing an open source, flexible, adaptable, cybersecure and multi-technology meta-Operating System, sustainable during and after the end of the project, via the Eclipse foundation (NEMO consortium member). To achieve technology maturity and massive adoption, NEMO will not "reinvent the wheel", but leverage and interface existing systems, technologies and Open Standards, and introduce novel concepts, tools, testing facilities/Living Labs and engagement campaigns to go beyond today's state of the art, make breakthrough research and create sustainable innovation, already within the project lifetime.<br>NEMO will introduce innovations at different layers of the protocol stack,<br>enabling on-device Cybersecure Federated ML/DRL,<br>deliver time-triggered (TSN) multipath ad-hoc/hybrid self-organized and zero-delay failback/self-healing multi-cloud clusters, multi-technology Secure Execution Environment and on-Service Level Objectives meta-Orchestrator, Plugin and Apps Lifecycle Management and Intent Based programming tools.<br>Moreover, NEMO will be "by design" and "by innovation" cybersecure and trusted adopting state of the art mechanisms such as Mutual TLS and Digital Identity Attestation.<br>NEMO will be validated in 5 most prominent industrial sectors (i.e., Farming, Energy, Mobility/City, Industry 4.0 and Media/XR) and 8 use cases in 5 +1 Living Labs, utilizing more than 30 heterogenous IoT devices and real 5G infrastructure. The impact will not only safeguard EU position in data economy and applications verticals, but lower energy efficiency, reduce pesticides and CO2 footprint.<br>Beyond Eclipse adoption, NEMO sustainability, wide acceptance and SMEs engagement will be achieved via open-source ecosystems, standardization initiatives and 2 Open Calls that will provide financial support of 1,8M€ and access to NEMO Living Labs to SMEs and enlarge NEMO by at least 16 new entities. |
| | First analysis | Capabilities:<br>• Federated meta Network Cluster Controller (mNCC) |


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| | | ▪ Network management for existing/emerging IoT/5G/6G technologies<br>▪ Time-triggered multipath/multitenant/multi-cloud clusters<br>▪ Support of zero-delay failback/self-healing "by design"<br>● Secure Execution Environment (SEE)<br>▪ Transparent sandbox creation<br>▪ Secure micro-services<br>▪ Unikernels (remote) execution |

### 3.3.6 Nephele

*Table 14 – MetaOS project: Nephele*

| | | |
|---|---|---|
| Nephele | Dates and URL | 01/09/2022 – 31/08/2025<br>*https://cordis.europa.eu/project/id/101070487*<br>*https://nephele-project.eu/* |
| | Contact point | Anastasios Tsafeir tzafeir@cn.ntua.gr<br>Dimitrios Soudris dimitrios.soudris@gmail.com (technical manager)<br>*ECLIPSE and ATOS are partners* |
| | Title | A lightweight software stack and synergetic meta-orchestration framework for the next generation compute continuum |
| | Objectives | The vision of NEPHELE is to enable the 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.<br>The NEPHELE project aims to introduce two core innovations, namely:<br>● an IoT and edge computing software stack for leveraging virtualization of IoT devices at the edge part of the infrastructure and supporting openness and interoperability aspects in a device-independent way. Through this software stack, management of a wide range of IoT devices and platforms can be realised in a unified way, avoiding the usage of middleware platforms, while edge computing functionalities can be offered on demand to efficiently support IoT applications' operations.<br>● a synergetic meta-orchestration framework for managing the coordination between cloud and edge computing orchestration platforms, through high-level scheduling supervision and definition, based on the adoption of a "system of systems" approach.<br>The NEPHELE outcomes are going to be demonstrated, validated and evaluated in a set of use cases across various vertical industries, including areas such as disaster management, logistic operations in ports, energy management in smart buildings and remote healthcare services. Two successive open calls will also take place, while a wide open-source community is envisaged to be created for supporting the NEPHELE outcomes. |



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| | | |
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| | First analysis | Capabilities<br>• IoT and edge software stack<br>▪ virtualization of IoT devices at the edge part<br>• Meta-orchestration framework<br>▪ coordination between cloud and edge computing orchestration platforms<br>▪ high-level scheduling supervision and definition |

## 3.4 Cognitive Cloud Projects

This section lists the research projects funded by CL4-2022-DATA-01-02 (Cognitive cloud)

### 3.4.1 SovereignEdge.Cognit

*Table 15 – Cognitive cloud project: SovereingEdge.Cognit*

| | | |
|---|---|---|
| SovereignEdge Cognit | Dates and URL | 01/01/2023 – 31/12/2025<br>*https://cordis.europa.eu/project/id/101092711*<br>*https://sovereignedge.eu/cognit/* |
| | Contact point | Alberto Marti amarti@opennebula.io |
| | Title | A Cognitive Serverless Framework for the Cloud-Edge Continuum |
| | Objectives | An effective platform for the cognitive cloud-edge continuum must address a number of unsolved challenges, many of them derived from constrained resource devices, infrastructure heterogeneity, and the need to meet criteria such as performance, resilience, security, data sovereignty, and energy efficiency. A disaggregated architecture is required, making use of AI, automation, and portability to manage and adapt resources and workloads, and to respond in real time to possible incidents and security threats.<br>Edge application developers willing to speed up computation, save energy, and cut costs will need a way to combine their edge devices with the many resources available across the cloud-edge continuum. This innovative approach requires computationally-intensive data processing functions to be easily executed outside edge devices, sensors, and actuators. It is with that vision in mind that this project proposes a **new distributed Function-as-a-Service (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. Our AI-enabled adaptive serverless framework will provide applications with **secure and portable access to a continuous data processing environment** that abstracts the large-scale, geo-distributed, and low-latency capabilities provided by the cloud-edge continuum. |



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| | | The Consortium combines innovative open source companies in Europe, high-impact research organizations, and several edge application providers. Our research will be validated in relevant application domains, and will establish an ecosystem with links to industrial initiatives. This project will be transformative for the emerging EU edge ecosystem, providing resources and knowledge for start-ups, SMEs, and industry leaders seeking to look beyond centralized platforms and hyperscalers. It will increase European autonomy not only in data processing but also in strategic edge technologies. |
| | Contribution to continuum | • Distributed Function-as-a-Service (FaaS) paradigm for edge application management and smart orchestration<br>• Secure and portable access to a continuous data processing environment |

### 3.4.2 AC3

*Table 16 – Cognitive cloud project: AC3*

| | | |
|---|---|---|
| AC3 | Dates and URL | 01/01/2023 – 31/12/2025<br>*https://cordis.europa.eu/project/id/101093129*<br>*https://www.isi.gr/project/agile-and-cognitive-cloud-edge-continuum-management* |
| | Contact point | Christos Verikoukis cveri@isi.gr |
| | Title | Agile and Cognitive Cloud edge Continuum management (AC3) |
| | Objectives | As modern applications require guaranteed low latency and massive data transfer rates, technology is being pushed to its limits, prompting a paradigm shift. To address these resource needs, IT computing platforms have evolved beyond the traditional central cloud/DC with high-capacity networking infrastructure to extend their coverage to the network edge and far edge. This new paradigm, called the cloud edge computing continuum (CECC), encompasses services that span from core cloud to edge and far edge. To manage and optimize resources efficiently through this new model, we propose an Agile and Cognitive Cloud-edge Continuum (AC3) management framework. This framework plays a crucial role in providing scalability, agility, effectiveness, and dynamicity in service delivery over the CECC infrastructure. It offers a secure federated platform that manages data sources, CECC resources, and application behavior in a unified and harmonized manner to ensure the desired SLA and save energy consumption. Furthermore, the AC3 platform can adapt to different contexts and network events, such as a lack of resources, data deluge, or mobility of data sources, by managing (i.e. deploying or migrating) micro-services across CECC infrastructures. AC3 leverages AI, ML, semantic and context-awareness algorithms to provide an efficient life cycle management system of services, data sources, and CECC resources to ensure low response time and high data rate while conserving energy. |



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| | | |
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| | Contribution to continuum | • Efficient and smart management framework for the computing continuum.<br>• Support scalable and agile service delivery over the edge-cloud continuum.<br>• Managing network events such as data deluge, lack of resources and mobility of data in the continuum.<br>• AC3 management framework leverages AI, semantic, and context aware algorithms to efficiently manage the continuum resources and services. |

### 3.4.3 ACES

*Table 17 – Cognitive cloud project: ACES*

| | | |
|---|---|---|
| ACES | Date and URL | 01/12/2023 – 30/11/2025<br>*https://cordis.europa.eu/project/id/101093126*<br>*https://iptc.upm.es/aces-autopoietic-cognitive-edge-cloud-services* |
| | Contact point | Fernando Ramos fvramos@tecnico.ulisboa.pt |
| | Title | Autopoietic Cognitive Edge-cloud Services (ACES) |
| | Objectives | The increasing need for cloud services at the edge (edge–services) is caused by the rapidly growing quantity and capabilities of connected and interacting edge devices exchanging vast amounts of data. This presents several challenges to cloud computing architectures at the edge, including ensuring end-to-end transaction resiliency for distributed microservices, managing increasing complexity, securely handling the east-west flow of sensitive data and applications, and ensuring transparency and explainability of AI in the edge-services platform. The ACES project aims to address these challenges by integrating autopoiesis and cognition into different levels of cloud management and empowering AI to perform functions such as workload placement, service and resource management, data and policy management, telemetry, and monitoring. The project aims to produce an autopoiesis cognitive cloud-edge framework, awareness tools, AI/ML agents, and a swarm technology-based methodology for orchestrating resources in the edge. Other expected outcomes include a workload placement and optimization service, an app store for AI models, and agents that ensure stability in situations of extreme load and complexity. ACES will be validated in three scenarios that demand highly decentralized computing and autonomic decision-making while reducing the costs and environmental impact of cloud-edge management. To promote the adoption of ACES outcomes beyond its lifespan, various activities are planned to reach a wider network of stakeholders in key sectors. |
| | Contribution to continuum (first analysis) | • autopoiesis cognitive cloud-edge framework.<br>• AI agents for workload placement, service and resource management, data and policy management, telemetry and monitoring.<br>• Agents safeguarding stability in situations of extreme load and complexity.<br>• Swarm technology-based methodology and implementation for orchestration of resources in the edge. |



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| | | |
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| | | • Edge-wide workload placement and optimization service.<br>• An app store for classification, storage, sharing and rating of AI models used in ACES. |

### 3.4.4 CloudSkin

*Table 18 – Cognitive cloud project: CloudSkin*

| | | |
|---|---|---|
| CloudSkin | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092646*<br>*https://cloudskin.eu/* |
| | Contact point | Marc Sanchez marc.sanchez@urv.cat<br>Joana Rodrigues (Technical Manager) |
| | Title | Adaptive virtualization for AI-enabled Cloud-edge Continuum (CloudSkin) |
| | Objectives | Currently, the vast majority of data processing and analysis occurs in cloud data centers, with only a small fraction taking place at the edge. This limited use of edge resources causes delays in decision-making and hinders business processes and intelligence from being conducted outside of data centers. This causes Europe to miss out on many opportunities to serve various industries and use cases in the coming years. To address this, CloudSkin aims to create a cognitive cloud continuum platform with three main features. Firstly, the platform will use AI/ML to optimize workloads, resources, energy, and network traffic, adapting quickly to changes in application behavior and data variability, and finding the right balance between the cloud and the edge. Secondly, the CloudSkin platform will enable users to achieve "stack identicality" across the cloud-edge continuum, ensuring that legacy software stacks, such as MPI programs, can run seamlessly at remote edges. To do this, CloudSkin will develop a new lightweight, portable virtualization abstraction and confidential abstractions to protect data in use. Thirdly, CloudSkin will help prepare the necessary infrastructure to integrate the new virtualized execution abstractions into the virtual resource continuum, especially for small tasks with fast data access and sharing requirements. The infrastructure will provide relevant control knobs to enable dynamic resource reconfiguration, as assisted by the AI/ML-based orchestration plane in the CloudSkin platform. Together, these innovations make up the strategic elements of the new "cognitive continuum for the cloud and edge" that CloudSkin envisions. |
| | Contribution to continuum | • Developing a **learning plane** to optimally orchestrate cloud-edge resources.<br>• Developing an abstraction called “Cloud edge cells” based on WebAssembly technology to enable the execution of the same computation on a wide range of cloud and embedded devices.<br>• Designing an infrastructure that supports (i) the execution of a variety of cloud-edge cells including extremely short-lived ones and (ii) different execution patterns like processing a burst of cells. |

### 3.4.5 CODECO


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*Table 19 – Cognitive cloud project: CODECO*

| | | |
|---|---|---|
| CODECO | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092696*<br>*https://www.fortiss.org/forschung/projekte/detail/codeco* |
| | Contact point | Rute Sofia sofia@fortiss.org<br>*ECLIPSE and ATOS are partners* |
| | Title | Cognitive Decentralised Edge Cloud Orchestration (CODECO) |
| | Objectives | CODECO is a management framework for Edge-Cloud that is cognitive, cross-layered, and highly adaptive. It features a unique orchestration approach that supports decentralized data workflows for data management and governance, dynamic offloading of computation and computation status, and adaptive networking services (TRL5). The framework is built around privacy-preserving decentralized learning mechanisms, which reduce latency and power consumption from the far Edge to Cloud. This allows real-time adjustments to available Edge-Cloud constraints, running services, and networking infrastructure that adapts to the needs of active services. The CODECO framework is designed to democratize technology and enable faster market adoption of the toolkit, as well as products and services derived from it. To achieve these goals, CODECO proposes several assets, including open, cognitive toolkits and smart Apps, a developer-oriented open-source software repository, training tools to support service development, use cases in smart cities, energy, manufacturing, and smart buildings, open calls, multiple community events, and integration with the large-scale EdgeNet experimental infrastructure to facilitate experimentation and novel concepts by the research community. |
| | Contribution to continuum | The main aspects of the research within the project are:<br>• **Automated configuration and cognitive edge cloud management** considering cross-layer behavior (application in the network), data and metadata management and policy enforcement. .<br>• **Privacy-preserving decentralized learning and contextual knowledge,** cross-layers and with a focus on federated learning approaches better suited to orchestrating data workflow computations and networks.<br>• **Dynamic scheduling and workload migration.** Addressing the challenges posed by increased levels of automation due to the mobility of containers and workloads between nodes in a single cluster and between different clusters.<br>• **Joint orchestration of compute and network resources.** On the one hand, the network infrastructure needs to be more flexible, intention and context driven, ie the network should be viewed and edited as a single system. On the other hand, common computational and networking paradigms that integrate aspects such as security/trust, mobility support, decentralized and flexible namespaces are key to building an intelligent, decentralized edge ecosystem.<br>• **Global perspective on data in the IoT-Edge-Cloud continuum.** Where is data stored, what are its properties, and what are the limitations on processing and replication of data? To achieve this, CODECO will collect and manage metadata ("data |



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| | | |
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| | | that provides information about other data") and make this metadata available to the orchestration and other system components. |

### 3.4.6 COGNIFOG

*Table 20 – Cognitive cloud project: Cognifog*

| | | |
|---|---|---|
| COGNIFOG | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092968*<br>*https://cognifog.eu/* |
| | Contact point | Azaiez Selma selma.azaiez@cea.fr<br>*ATOS is a partner* |
| | Title | AI-empowered Edge Cloud Continuum for Self-aware Cognitive Computing Environments (COGNIFOG) |
| | Objectives | The emergence of next-generation technologies such as IoT, AI, and cloud computing presents promising solutions to tackle some of the world's most pressing societal, environmental, and economic issues. However, these technologies also come with significant data management challenges. IDC predicts that the total amount of data generated by connected devices will surpass 40 trillion gigabytes by 2025. Currently, most data storage and analysis occur in centralized cloud locations, putting a strain on network capacity and creating single points of failure during crises like natural disasters and health emergencies. To address these challenges, COGNIFOG proposes a Cognitive Fog Framework that can reduce energy consumption and latency in next-generation IT systems by analyzing data at the edge, closer to where they are generated, instead of routing them through communication networks to a data center. This framework will also provide a cognitive, self-adaptive infrastructure that can dynamically provision computing, storage, and networking resources along the far-edge-to-edge-to-cloud path with minimal human intervention. In addition, COGNIFOG aims to ensure European leadership by providing an open, interoperable framework with APIs for application developers to create and deploy applications on top of heterogenous IoT/IT systems. The project will validate its results in three representative application domains: critical collaboration missions, smart health, and smart industry. With a consortium of 12 European partners, COGNIFOG will be a cornerstone in the cognitive fog computing domain. |
| | Contribution to continuum | • adaptive and modular edge-cloud continuum framework.<br>• orchestration capabilities supporting heterogeneous resources, real-time, scalability and AI-based monitoring for improved privacy, security, reliability, resilience and safety.<br>• load balancing and energy management capabilities. |

### 3.4.7 DECICE

*Table 21 – Cognitive cloud project: Decice*

| | | |
|---|---|---|
| DECICE | Dates and URL | 01/12/2022---30/11/2025<br>*https://cordis.europa.eu/project/id/101092582* |


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| | | |
|---|---|---|
| | | *https://decice.eu/* |
| | Contact point | Sabri Pllana Sabri.Pllana@forschung-burgenland.at |
| | Title | Device-Edge-Cloud Intelligent Collaboration framEwork (DECICE) |
| | Objectives | DECICE is a project that aims to create a cloud management framework using artificial intelligence that is open, portable, and adaptable for optimizing and deploying applications across a range of infrastructures, from high-performance computing systems to small IoT sensors at the edge.<br><br>To effectively manage such a diverse range of systems, the management plane needs to be intelligent and have advanced capabilities to adjust workloads proactively based on various needs, including latency, compute power, and power consumption. DECICE plans to use an AI model that creates a digital twin of available resources to make real-time scheduling decisions using telemetry data.<br><br>The framework will be able to balance workloads dynamically, optimize resource throughput and latency for performance and energy efficiency, and adapt quickly to changing conditions. DECICE will also provide administrators and deployment experts with the necessary tools and interfaces to control infrastructure components to achieve desired results.<br><br>The DECICE framework will integrate with orchestration systems using open standard APIs, making it portable, modular, and extensible. |
| | Contribution to continuum | • Computing continuum solution ranging from cloud and HPC to edge and IoT.<br>• Scheduler for dynamic load balancing enabling energy-efficient compute orchestration, improved use of green energy, and automated deployment<br>• API based control over network, computing and data resources supporting constraint and non-functional behavior specification<br>• Dynamic digital twin with AI-based prediction capabilities<br>• Service deployment enabler with a high level of trustworthiness and compliance with relevant security frameworks. |

### 3.4.8 EDGELESS

*Table 22 – Cognitive cloud project: Edgeless*

| | | |
|---|---|---|
| EDGELESS | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092950*<br>*https://edgeless-project.eu/* |
| | Contact point | Antonio Paradell Bondia antonio.paradell@worldline.com<br>*ATOS is a partner* |
| | Title | Cognitive Edge-cloud with Serverless Computing (EDGELESS) |
| | Objectives | The objective of the EDGELESS project is to utilize the serverless approach throughout all layers of the edge-cloud continuum to take |


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| | | full advantage of various decentralized computational resources that are available on-demand in close proximity to where data is generated or utilized. The project focuses on enabling a horizontal pooling of resources on edge nodes, which have limited capabilities or specialized hardware, integrated seamlessly with cloud resources. This represents a significant improvement compared to the traditional vertical offloading solutions, where the edge is treated as a supplement to the cloud, and is expected to be more effective and transparent. The goals of this project are to:<br>• Efficiently operate data-intensive applications with dynamic behavior throughout the edge-cloud continuum, even with resource-constrained and heterogeneous edge computing resources that are subject to fast changing conditions.<br>• Develop cognitive tools and techniques that enable efficient use of resources in networks of constrained and specialized edge nodes while taking into account computation needs and performance. This should ensure optimal implementation of function-oriented execution.<br>• Allow trusted access to lambda functions running on edge nodes, including those with limited computational capabilities. This will facilitate a decentralized exchange of trusted data and computations by leveraging certified hardware security.<br>• Establish interfaces and models for deploying edge applications in a multi-provider environment that spans the continuum, while adhering to specific functional and non-functional requirements, and ensuring the highest level of quality of service (QoS).<br>• Test and evaluate the solution in a wide range of realistic use cases that have diverse requirements. |
| | Contribution to continuum | • State management framework at the edge<br>• Small device hypervisor CAM<br>• Specialised HW serverless executor<br>• Trusted environment for serverless function<br>• Physically-isolated secure elements<br>• ε-controller<br>• ε-orchestrator<br>• SLA in serverless and edge/cloud context<br>• Data-centric, collaborative function and service middleware framework for IoRT<br>• Smart city surveillance<br>• Activity identification and Anomaly detection |

### 3.4.9 MLSysOps

*Table 23 – Cognitive cloud project: MLSysOps*

| | | |
|---|---|---|
| MLSysOps | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092912*<br>*https://mlsysops.eu/* |
| | Contact point | Spyros Lalis lalis@uth.gr |
| | Title | Machine Learning for Autonomic System Operation in the Heterogeneous Edge-Cloud Continuum (MLSysOps) |



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| | | |
|---|---|---|
| | Objectives | MLSysOps will achieve substantial research contributions in the realm of AI-based system adaptation across the cloud-edge continuum by introducing advanced methods and tools to enable optimal system management and application deployment.<br><br>MLSysOps will design, implement and evaluate a complete framework for autonomic end-to-end system management across the full cloud-edge continuum<br><br>MLSysOps will employ a hierarchical agent-based AI architecture to interface with the underlying resource management and application deployment/orchestration mechanisms of the continuum. Adaptivity will be achieved through continual ML model learning in conjunction with intelligent retraining concurrently to application execution, while openness and extensibility will be supported through explainable ML methods and an API for pluggable ML models.<br><br>Flexible/efficient application execution on heterogeneous infrastructures and nodes will be enabled through innovative portable container-based technology.<br><br>Energy efficiency, performance, low latency, efficient, resilient and trusted tier-less storage, cross-layer orchestration including resource-constrained devices, resilience to imperfections of physical networks, trust and security, are key elements of MLSysOps addressed using ML models.<br><br>The framework architecture disassociates management from control and seamlessly interfaces with popular control frameworks for different layers of the continuum.<br><br>The framework will be evaluated using research testbeds as well as two real-world application-specific testbeds in the domain of smart cities and smart agriculture, which will also be used to collect the system-level data necessary to train and validate the ML models, while realistic system simulators will be used to conduct scale-out experiments.<br><br>The MLSysOps consortium is a balanced blend of academic/research and industry/SME partners, bringing together the necessary scientific and technological skills to ensure successful implementation and impact. |
| | Contribution to continuum | • Open AI-ready, agent-based framework for holistic, trustworthy, scalable, and adaptive system operation across the heterogeneous cloud-edge continuum.<br>• AI architecture supporting explainable, efficiently retrainable ML models for end-to-end autonomic system operation in the cloud-edge continuum.<br>• Enabler for efficient, flexible, and isolated execution across the heterogeneous continuum.<br>• Enabler to support green, resource-efficient, and trustworthy system operation, while satisfying application QoS/QoE requirements.<br>• Enabler for realistic model training, validation, and evaluation. |

## 3.5 Swarm Computing Projects



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This section lists the research projects funded by CL4-2022-DATA-01-02 (Programming tools for decentralised intelligence and swarms (RIA))

### 3.5.1 INCODE

*Table 24 – Swarm computing cloud project: INCODE*

| | | |
|---|---|---|
| INCODE | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101093069* |
| | Contact point | John Avramidis avramidis.john@gmail.com |
| | Title | Programming Platform for Intelligent Collaborative Deployments over Heterogeneous Edge-IoT Environments |
| | Objectives | INCODE envisions the design and development of an 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.<br>The platform is implemented following three innovative design approaches:<br>• The deployment and management of the applications is conducted by an orchestration framework that follows a vertical layered approach from the end user interface to the infrastructure management while spanning horizontally across the device-edge-core-cloud continuum. The deployment follows the user-defined networking and operational features of the application in its northbound interface and a tight integration with state-of-the-art IoT, edge/cloud computing, and networking platforms in its southbound interface through a well-define driver API framework. With this approach the full programmability and reconfigurability of resources across the continuum is enabled.<br>• An open and extensible, programming toolset facilitates application development and deployment for large swarms of devices at the edge through a multi-role Internal Developer Platform (IDP) and new feature development and testing,<br>• A secure and trusted framework for registering and authenticating IoT device and edge nodes entering the system as well as the data sharing and application deployment.<br>The concept is tested and validated over a mature testing environment that integrates diverse IoT application areas in smart logistics, manufacturing, utility inspection, and community PPDR over a programable infrastructure extended to O-RAN, 5G, SDN enable core Cloud.<br>The consortium addresses all the required development sectors from the platform technology innovations, to supported IoT infrastructure and applications, including the end user interfacing and resource management intelligence. |
| | Contribution to continuum | • Orchestration framework across continuum<br>• Programmability and reconfigurability of continuum resources based on northbound and southbound interface |



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| | | |
|---|---|---|
| | | • Secure and trusted framework for IoT devices and edge nodes |

### 3.5.2 OASEES

*Table 25 – Swarm computing cloud project: OASEES*

| | | |
|---|---|---|
| OASEES | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092702*<br>*https://oasees-project.eu/* |
| | Contact point | Akis Kourtis akis.kourtis@iit.demokritos.gr |
| | Title | Open Autonomous programmable cloud appS & smart EdgE Sensors |
| | Objectives | The massive increase in device connectivity and generated data has resulted in the proliferation of intelligent processing services to create insights and exploit data in a multi-modal manner. Currently, the most powerful data processing operates in a centralized manner at the cloud, which provides the ability to scale and allocate resources on demand and efficiently.<br>Centralized processing and cloud hosting, bound and limit their services and applications to operate in a resource restricted manner, relying usually on large single entities to provide, i) Authentication, ii) Data storage, iii) Data processing, iv) Connectivity, v) Vendor-locked environments for development and orchestration.<br>This significantly limits the user from its data governance and even identity management. Similarly, existing solutions for edge device authentication require a centralized entity to trust them and authenticate them, rendering a non-portable identification paradigm.<br>OASEES aims to create an open, decentralized, intelligent, programmable edge framework for Swarm architectures and applications, leveraging<br>• the Decentralized Autonomous Organization (DAO) paradigm, and<br>• integrating Human-in-the-Loop (HITL) processes for efficient decision making.<br>The OASEES vision is to provide the open tools and secure environments for swarm programming and orchestration for numerous fields, in a completely decentralized manner.<br>An important aspect in this process is identification and identity management, in which OASEES targets the implementation of a portable and privacy preserving ID federation system, for edge devices and services, with full compliance and compatibility to GAIA-X federation and IDSA trust directives and specifications.<br>This situation solidifies the need for an integrated enabler framework tailored to the edge's extreme data processing demands, using different edge accelerators, i.e. GPU, NPU, SNN and Quantum. |
| | Contribution to continuum | • open tools and secure environment for swarm programming and orchestration<br>• Identity management<br>• Integrated enabler framework using edge accelerators |



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### 3.5.3 OpenSwarm

*Table 26 – Swarm computing cloud project: OpenSwarm*

| | | |
|---|---|---|
| OpenSwarm | Dates and URL | 01/01/2023---30/04/2026<br>*https://cordis.europa.eu/project/id/101093046*<br>*http://openswarm.eu/* |
| | Contact point | Thomas Watteyne thomas.watteyne@inria.fr |
| | Title | Orchestration and Programming ENergy-aware and collaborative Swarms With AI-powered Reliable Methods |
| | Objectives | Low-power wireless technology tends to be used today for simple monitoring applications, in which raw sensor data is reported periodically to a server for analysis.<br>The ambition of the OpenSwarm project is to trigger the next revolution in these data-driven systems by developing true collaborative and distributed smart nodes, through groundbreaking R&I in three technological pillars: efficient networking and management of smart nodes, collaborative energy-aware Artificial Intelligence (AI), and energy-aware swarm programming.<br>Results are implemented in an open software package called "OpenSwarm", which is verified in our labs on two 1,000 node testbeds.<br>OpenSwarm is then validated in five real-world proof-of-concept use cases, covering four application domains:<br>• Renewable Energy Community (Cities & Community),<br>• Supporting Human Workers in Harvesting (Environmental),<br>• Ocean Noise Pollution Monitoring (Environmental),<br>• Health and Safety in Industrial Production Sites (Industrial/Health),<br>• Moving Networks in Trains (Mobility).<br>A comprehensive dissemination, exploitation, and communication plan (including a diverse range of activities related to standardization, educational and outreach, open science, and startup formations) amplifies the expected impacts of OpenSwarm, achieving a step change enabling novel, future energy-aware swarms of collaborative smart nodes with wide range benefits for the environment, industries, and society. |
| | Contribution to continuum | • efficient networking and management of smart nodes<br>• collaborative energy-aware Artificial Intelligence (AI), and<br>• energy-aware swarm programming |

### 3.5.4 SmartEdge

*Table 27 – Swarm computing cloud project: SmartEdge*


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| | | |
|---|---|---|
| SmartEdge | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092908*<br>*https://www.smart-edge.eu/* |
| | Contact point | Filippo Cugini filippo.cugini@cnit.it |
| | Title | Semantic Low-code Programming Tools for Edge Intelligence |
| | Objectives | The objective of the SMARTEDGE project is to enable the dynamic integration of decentralised edge intelligence at runtime while ensuring reliability, security, privacy and scalability. We will achieve this by enabling a semantic-based interplay of the edge devices of such systems via a cross-layer toolchain that facilitates the seamless and real-time discoverability and composability of autonomous intelligence swarm. Hence, an application can be freely built by distributing the processing, data fusion and control across heterogeneous sensors, devices and edges with ubiquitous low-latency connectivity.<br>The goal of this project is to develop a SMARTEDGE solution with a low-code tool programming environment with various tools:<br>• Continuous Semantic Integration (CSI);<br>• Dynamic Swarm Network (DSW); and<br>• Low-code Toolchain for Edge Intelligence.<br>CSI allows the SMARTEDGE solution to interact with devices according to a<br>• standardized semantic interface, via a<br>• continuous conversion process based on declarative mappings and scalable from edge to cloud, and<br>• providing a declarative approach for the creation and orchestration of apps based on swarm intelligence.<br>DSW provides<br>• automatic discovery and dynamic network swarm formation in near real time,<br>• hardware-accelerated in-network operations for context-aware swarm networking, and<br>• embedded network security.<br>The low-code tool chain provides<br>• semantic-driven multimodal stream fusion for Edge devices;<br>• swarm elasticity via Edge-Cloud Interplay;<br>• adaptive coordination and optimization;<br>• cross-layer toolchain for Device-Edge-Cloud Continuum.<br>The SMARTEDGE solution will be comprehensively demonstrated over four application areas: automotive, city, factory and heath via the strong collaboration of eight industrial partners, Dell, Siemens, Bosch, IMC, Conveq, Cefiel and NVIDIA with eight research institutes. |
| | Contribution to continuum | • Continuous Semantic Integration (CSI) supporting the continuum<br>Dynamic Swarm Network (DSW); provides<br>• automatic discovery and dynamic network swarm formation in near real time, |



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| | | |
|---|---|---|
| | | • hardware-accelerated in-network operations for context-aware swarm networking, and<br>• embedded network security.<br>• Low-code Toolchain for Edge Intelligence including swarm and cross-layer toolchain for Device-Edge-Cloud Continuum. |

### 3.5.5 TaRDIS

*Table 28 – Swarm computing cloud project: TaRDIS*

| | | |
|---|---|---|
| TaRDIS | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101093006*<br>*https://www.project-tardis.eu/* |
| | Contact point | Carla Ferreira carla.ferreira@fct.unl.pt |
| | Title | Trustworthy and Resilient Decentralised Intelligence for Edge Systems |
| | Objectives | Developing and managing distributed systems is a complex task requiring expertise across multiple domains. This complexity considerably increases in swarm systems, which are highly dynamic and heterogeneous and require decentralised solutions that adapt to highly dynamic system conditions.<br>The project TaRDIS focuses on supporting the correct and efficient development of applications for swarms and decentralised distributed systems, by combining a novel programming paradigm with a toolbox for supporting the development and executing of applications.<br>TaRDIS proposes a language-independent event-driven programming paradigm that exposes, through an event-based interface, distribution abstractions and powerful decentralised machine learning primitives.<br>The programming environment will assist in building correct systems by taking advantage of behavioural types to automatically analyse the component's interactions to ensure correctness-by-design of their applications, taking into account application invariants and the properties of the target execution environment.<br>TaRDIS underlying distributed middleware will provide essential services, including data management and decentralised machine learning components. The middleware will hide the heterogeneity and address the dynamicity of the distributed execution environment by orchestrating and adapting the execution of different application components across devices in an autonomic and intelligent way.<br>TaRDIS results will be integrated in a development environment, and also as standalone tools, both of which can be used for developing applications for swarm systems.<br>The project results will be validated in the context of four different use cases provided by high impact industrial partners that range from swarms of satellites, decentralised dynamic marketplaces, decentralised machine learning solutions for personal-assistant applications, and the distributed control process of a smart factory. |



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| | | |
|---|---|---|
| | Contribution to continuum | Novel programming paradigm with a toolbox for supporting the development and executing of applications:<br>• event-driven programming paradigm<br>• behavioural type<br>• middleware integrating data management and distributed ML compoenets, and dynamic orchestration |

## 3.6 Open Source for Cloud Services Projects

This section lists the research projects funded by CL4-2022-DIGITAL-EMERGING-01-26

### 3.6.1 Aero

*Table 29 – Swarm computing cloud project: Aero*

| | | |
|---|---|---|
| Aero | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092850* |
| | Contact point | Dionisios Pnevmatikatos pnevmati@cslab.ece.ntua.gr |
| | Title | Accelerated EuROpean clOud |
| | Objectives | Several European flagship projects have emerged towards European sovereignty in chip design and computing infrastructure. Among them, the EU Processor Initiative (EPI) spearheads the development of the first EU processor.<br>To ensure the successful integration of the EU processor into the cloud computing ecosystem and strengthen even more EU data sovereignty, it is necessary to develop the software support at the same pace with the hardware development.<br>The harmonic relationship of the developed software and hardware is of paramount importance in order to establish an EU cloud platform able to compete with the mainstream solutions which are currently delivered by US companies.<br>AERO aims to upbring and optimize an 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.<br>The AERO software stack combines the aforementioned software components with novel software and hardware interfaces as a means to seamlessly exploit the heterogeneity aspects of the EU processor with regards to high performance, energy efficiency, and security.<br>The ultimate objective of AERO is to facilitate easy migration of existing cloud customers to a cloud infrastructure that harnesses the capabilities of the EU processor. To showcase early adoption and the potential business value, the developed software and hardware technologies will be piloted by use cases representative of important EU industrial domains, such as automotive and space exploration. |



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| | | |
|---|---|---|
| | Contribution to continuum | • Software support for EU cloud processor |

### 3.6.2 OpenCube

*Table 30 – Swarm computing cloud project: OpenCube*

| | | |
|---|---|---|
| OpenCube | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092984* |
| | Contact point | Bo peng bopeng@kth.se<br>Stefano Markidis markidis@kth.se |
| | Title | Open-Source Cloud-Based Services on EPI Systems |
| | Objectives | This project proposes to design OpenCUBE, a full-stack solution of a validated European Cloud computing blueprint to be deployed on European hardware infrastructure.<br>OpenCUBE will develop a custom cloud installation with the guarantee that an entirely European solution like SiPearl processors and Semidynamics RISC-V accelerators can be deployed reproducibly.<br>OpenCUBE will be built on industry-standard open APIs using Open Source components and will provide a unified software stack that captures the different best practices and open source tooling on the operating system, middleware, and system management level.<br>It will thus provide a solid basis for the European cloud services, research, and commercial deployments envisioned to be core for federated digital services via Gaia-X.<br>To remain competitive for the European Green Deal, OpenCUBE is designed to make energy awareness a core feature at all levels of the stack, exploiting the advanced features of the SiPearl Rhea processor family at the hardware level and exposing the necessary API at the site level, up to and including interfaces to the electricity grid.<br>This project will leverage representative workloads like those of ECMWF characteristics for production and Digital Twin workflows as drivers for the design and deployment of the cluster infrastructure.<br>We will collaborate closely with the projects developing the virtual environments and the open hardware interfaces for current and future European processor and coprocessor technology. |
| | Contribution to continuum | • full-stack solution of a cloud computing blueprint |

### 3.6.3 RISER

*Table 31 – Swarm computing cloud project: RISER*


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| | | |
|---|---|---|
| RISER | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101092993*<br>*https://www.riser-project.eu/20230101site/* |
| | Contact point | Manolis Marazakis maraz@ics.forth.gr |
| | Title | RISC-V for Cloud Services |
| | Objectives | Building on top of outcomes from the EPI and EUPilot projects, RISER will develop the first all-European RISC-V cloud server infrastructure, significantly enhancing Europe's open strategic autonomy. RISER will leverage and validate open hardware high-speed interfaces combined with a fully-featured operating system environment and runtime system, enabling the integration of low-power components, including the RISC-V processor chips from EPI and EUPilot and LPDDR4 memories, in a novel energy-efficient cloud architecture.<br>RISER brings together a set of 7 partners from industry and academia to jointly develop and validate open-source designs for standardized form-factor system platforms suitable for supporting cloud services. Specifically, RISER will build the following two cloud infrastructures:<br>• An accelerator platform, which includes the ARM-based RHEA processor from EPI and a PCIe acceleration board that will be developed within the project which will integrate up-to four RISC-V based EPI and EUPilot chips.<br>• A microserver platform, which interconnects up to ten microserver boards all developed by the project, each one supporting up to four RISC-V chips coupled with high-speed storage and networking. Embracing hyperconvergence, the microserver architecture will allow for distributed storage and memory to be used by any processor in the system with very low overhead.<br>The open-source system board designs of RISER will also be accompanied by open-source low-level firmware and systems software, and a representative Linux-based software stack to support cloud services. To evaluate and demonstrate the capabilities of the RISER platforms we will develop three use cases:<br>• Acceleration of compute workloads,<br>• Networked object and key-value storage, and<br>• Containerized execution as part of a provider-managed IaaS environment.<br>RISER will offer open access to the microserver platform, facilitating uptake and enhancing the commercialization path of project results. |
| | Contribution to continuum | RISER will build two cloud-focused platforms for RISC(V:<br>• An accelerator platform<br>• A microserver platform |

### 3.6.4 Vitamin-V

*Table 32 – Swarm computing cloud project: Vitamin-V*

| | | |
|---|---|---|
| Vitamin-V | Dates and URL | 01/01/2023---31/12/2025<br>*https://cordis.europa.eu/project/id/101093062* |


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| | | |
|---|---|---|
| | | *https://vitamin-v.upc.edu/* |
| | Contact point | Ramon Canal rcanal@ac.upc.edu |
| | Title | Virtual Environment and Tool-boxing for Trustworthy Development of RISC-V based Cloud Services |
| | Objectives | Vitamin-V aims to develop a complete 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.<br><br>Specifically, commercial cloud systems make use of hardware features that are currently unavailable in RISC-V virtual environments (not to mention the lack of specific RISC-V hardware). These features include the virtualization, cryptography and vectorization for which Vitamin-V will add support in three virtual environments: QEMU, gem5 and cloud-FPGA prototype platforms. Vitamin-V focuses and will provide support for EPI-based RISC-V designs for both the main CPUs and cloud-important accelerators (for memory compression). We will add the compiler (LLVM-based) and toolchain support for the ISA extensions. Moreover, novel approaches for the validation, verification, and test of software trustworthiness will be developed considering.<br><br>Vitamin-V will port and evaluate several cutting-edge VMMs and container suites (i.e. VOSySmonitor, KVM, QEMU, Docker, RustVMM, Kata containers), cloud management software (i.e. OpenStack, and Kubernetes) together with their software and libraries dependencies (e.g. JVM, Python); and AI (i.e Tensorflow) and BigData applications (Apache Spark). These software suites are representative of the three cloud setups that will be demonstrated: classical (OpenStack), modern (Kubernetes), and serverless (RustVMM, Kata, Kubernetes).<br><br>The cloud setups will be benchmarked against relevant AI (i.e. Google Net, ResBet, VGG19), BigData (TPC-DS), and Serverless applications (FunctionBench, ServerlessBench). Vitamin-V aims to match the software performance of its x86 equivalent while contributing to RISC-V open-source virtual environments, software validation and cloud software suites. |
| | Contribution to continuum | • support for EPI-based RISC-V |

## 3.7 Other Research Projects

### 3.7.1 SPADE (Drone project)

SPADE is a project in the CL6-2021-GOVERNANCE-01-21 topic (Potential of drones as multi-purpose vehicle – risks and added values)

*Table 33 – Drone project: SPADE*


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| | | |
|---|---|---|
| Spade | Dates and URL | 01/09/2022---31/08/2026<br>*https://cordis.europa.eu/project/id/101060778*<br>*https://spade-horizon.eu/* |
| | Contact point | Costas Davarakis cdavarakis@nydorsystem.com<br>*ECLIPSE and Trialog are partners of the project* |
| | Title | multi-purpoSe Physical-cyber Agri-forest Drones Ecosystem for governance and environmental observation |
| | Objectives | The strategic objective of SPADE is to develop an Intelligent Ecosystem to address the multiple purposes concept in the light of deploying UAVs to promote sustainable digital services for the benefit of a large scope of various end users in the sectors of agriculture, forestry, and livestock.<br>This includes individual UAV usability, UAV type applicability (e.g. swarm, collaborative, autonomous, tethered), UAV governance models availability and trustworthiness.<br>Multi-purposes will be further determined in the sensing dataspace reusability based on trained AI/Machine Learning (ML) models. These will enable sustainability and resilience of the overall life cycle of developing, setting up, offering, providing, testing, validating, refining as well as enhancing digital transformations and 'innovation building' services in Forestry, Cropping and Livestock Farming.<br>Pilot prototypes will contribute towards greater challenges such as deforestation, precision cropping and animal welfare.<br>First, SPADE will create a digital platform that is able to realise the potential benefits to be reaped from the use of drones. This platform is making drone operations better accessible and controllable, as well as providing a service channel for value added services enabled by drones.<br>Second, SPADE is demonstrating three innovative use cases of drones making use of the digital platform. While demonstrating the use cases, the benefits coming from the use of drones are analysed and quantified, on a detailed stakeholder level basis. This will demonstrate the new business opportunities. The demonstrations/pilots will also serve as an analysis platform to investigate the regulatory framework at international and national level. Open calls will provide 12 further use cases.. |
| | Contribution to continuum | • Digital twin for drones leveraging the continuum<br>• Support of security and privacy |

### 3.7.2 TEADAL (Data space project)

TEADAL is a project in the HORIZON-CL4-2021-DATA-01-01 - Technologies and solutions for compliance, privacy preservation, green and responsible data operations (AI, Data and Robotics Partnership) (RIA)

*Table 34 – Data space project: TEADAL*



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| | | |
|---|---|---|
| TEADAL | Dates and URL | 01/09/2022---31/08/2025<br>*https://cordis.europa.eu/project/id/101070186*<br>*https://www.teadal.eu/* |
| | Contact point | Amrita Prasad amrita.prasad@martel-innovate.com<br>*Martel is a partner in the project* |
| | Title | Trustworthy, Energy-Aware federated DAta Lakes along the computing continuum |
| | Objectives | Data analytics is one of the main cornerstones in many enterprise architectures and the data lake paradigm is more and more adopted to assist organizations in taking reliable, accurate, and fast decisions. Although the initial approaches to address these issues saw the data lakes as the evolution of data warehouses to be implemented on-premises, cloud providers are nowadays including in their offerings platforms able to setup and run them. Nevertheless, the increasing amount of data generated at the edge and the need to enable the data sharing among organizations are posing new challenges in terms of performances, energy efficiency, and privacy/confidentiality which can be properly addressed with data lakes which are deployed along the whole computing continuum as well as building a federation of such data lakes.<br>The ambition of TEADAL is to provide key cornerstone technologies to create stretched data lakes spanning the cloud-edge continuum and multi-cloud, providing privacy, confidentiality, and energy-efficient data management. The TEADAL data lake technologies will enable trusted, verifiable and energy efficient data flows, both in a stretched data lake and across a trustworthy mediatorless federation of them, based on a shared approach for defining, enforcing, and tracking privacy/confidentiality requirements balanced with the need for energy reduction. |
| | Contribution to continuum | • Data lakes solutions enabling data handling across the computing continuum<br>• Trustworthiness along the continuum<br>• Energy-efficient federation of stretched data lakes<br>• Privacy preserving federation of stretched data lakes |

### 3.7.3 TRUSTEE (Data space project)

TRUSTEE is a project in the HORIZON-CL4-2021-DATA-01-01 - Technologies and solutions for compliance, privacy preservation, green and responsible data operations (AI, Data and Robotics Partnership) (RIA)

*Table 35 – Data space project: TRUSTEE*

| | | |
|---|---|---|
| TRUSTEE | Dates and URL | 01/06/2022---31/12/2025<br>*https://cordis.europa.eu/project/id/101070214*<br>*https://horizon-trustee.eu/* |
| | Contact point | Maria Angela Kerkezou m.kerkezou@adrestia.eu |


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| | | |
|---|---|---|
| | Title | Trust & Privacy Preserving Computing Platform For Cross-Border Federation Of Data |
| | Objectives | As we live in a data-driven era, the emergence of interdisciplinary, geographically dispersed, data repositories, is inevitable. The fact that these repositories do not necessarily abide with existing interdisciplinary data representation standards, nor do they necessarily belong to any data federation initiative, renders them unusable, since researchers cannot easily access this data. Moreover, most of the times, integrity, privacy, and security in such interactions is either very difficult, or impossible to maintain. Towards this end, TRUSTEE aims to bring a green, secure, trustworthy, and privacy-aware framework that will aggregate various interdisciplinary data repositories, such as Healthcare, Education, Energy, Space, Automotive, Cross-border etc. and also consider other European data federation spaces and trans-national initiatives, such as Gaia-X and EOSC.<br><br>TRUSTEE will offer a secure-by-design framework, wherein stored data is homomorphically encrypted, thus offering researchers<br>• ability to search and use data in the encrypted domain<br>• a unified and meaningful FAIR representation of data, in an open and fair manner<br>• complex and context-aware queries through advanced ontologies,<br>• data processing and analysis through transparent trustworthy ML workflows, over an intuitive AI playground, which will promote AI eXplainability, interoperability, and re-usability, by utilizing state of the art methods and paradigms<br>• compliance with European privacy and ethical frameworks, e.g. GDPR, PIA, etc.,<br>• enforce privacy by applying a Homomorphic encryption layer, through which all data interaction will take place,<br>• a blockchain-based transaction recorder to ensure accountability.<br><br>TRUSTEE's fully encrypted solution will be validated through six different use cases supporting GAIA-X, EOSC, EGI, etc. demonstrating a multi-disciplinary, Pan-European federated FAIR and private data ecosystem. |
| | Contribution to continuum | • secure-by-design framework, wherein stored data is homomorphically encrypted |

### 3.7.4 CONNECT (CCAM project)

CONNECT is a project in the CL5-2021-D6-01-04 topic (Cyber secure and resilient CCAM (CCAM Partnership)

*Table 36 – Cooperative, connected and automated mobility project: CONNECT*

| | | |
|---|---|---|
| Spade | Dates and URL | 01/09/2022---31/08/2025<br>*https://cordis.europa.eu/project/id/101069688*<br>*https://spade-horizon.eu/* |
| | Contact point | Thanassis Giannetsos agiannetsos@ubitech.eu<br>*Trialog is a partner of the project* |


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| | | |
|---|---|---|
| | Title | |
| | Objectives | CONNECT addresses the convergence of security and safety in CCAM by assessing dynamic trust relationships and defining a trust reasoning framework based on which involved entities can establish trust for cooperatively executing safety-critical functions. This will enable both<br>• cyber-secure data sharing between data sources in the CCAM ecosystem that had no or insufficient pre-existing trust relationship, and<br>• outsourcing tasks to the MEC and cloud in a trustworthy way. Beyond the needs of functional safety, trustworthiness management should be included in CCAM's security functionality solution for verifying trustworthiness of transmitting stations and infrastructure.<br>CONNECT will build upon and expand the Zero Trust concept to tackle the issue of how to bootstrap vertical trust from the application, the execution environment and device hardware from the vehicle up to MEC and cloud environments. This includes measuring the system when instantiating network functions and determining the integrity and origin of software.<br>Trusted Execution Environments (TEEs), as sw- or hw-based security elements, will be essential to establish a verifiable chain of trust throughout the entire application stack of the host vehicle, as well as protecting data in transit, at rest and in use. By coupling the Zero Trust security principle with the need of "Never Trust, Always Verify", CONNECT bootstraps vertical trust for all users, devices and systems in the CCAM ecosystem by enabling continuous authorization and authentication prior to be granted access to data or resources.<br>Through TEE-enabled "Chip-to-Cloud"" assurances and verifiable chain of trust, CONNECT reaches its full potential: not only does it mitigates risks stemming from the Zero Trust CCAM environment but also ensures resilience.<br>This can make CONNECT the cornerstone of future smart transportation as it will usher new levels of safety and connectivity and bring vehicles even close to autonomy |
| | Contribution to continuum | • Decentralised trust on a multi access edge computing (MEC)<br>• Support of subjective logic |

## 3.8 Completed Research Projects

In addition to the cited projects, OpenContinuum will verify if the ecosystem has to be extended to completed projects stakeholders. The below projects were mentioned in a deliverable from the H-Cloud support action.

### 3.8.1 DECODE (Data space project)

DECODE is a completed project in the ICT-12-2018 Net innovation initiative topic



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*Table 37 – Cloud project: DECODE*

| | | |
|---|---|---|
| DECODE<br>Referenced in H-Cloud deliverable D1.2 | Dates and URL | 1/12/2016 – 31/12/2019<br>*https://cordis.europa.eu/project/id/732546*<br>*https://decodeproject.eu/* |
| | Title | Decentralised Citizens Owned Data Ecosystem |
| | Objective | Ease the management of private data, credential-based authentication and secure storage across distributed networks.<br>Allow non-technical operators to write and review smart rules running on any device for end-to-end encryption.<br>Allow smart rules to access private data based on entitlements and matched attributes<br>Allow everyone to record entitlements on a distributed ledger whose integrity is resilient and verifiable<br>*https://decodeproject.eu/publications/final-version-decode-architecture-documentation-and-sustainability.html* |
| | Value to continuum computing | Digital commons, Human readable language for data transformation (Zencode), Lightweight, portable and secure virtual-machine to execute Zencode (Zenroom)<br>*https://decodeproject.eu/publications/final-version-decode-architecture-documentation-and-sustainability.html*<br>Data governance<br>*https://decodeproject.eu/publications/common-knowledge-citizen-led-data-governance-better-cities.html* |

### 3.8.2 RADON (Cloud project)

RADON is a completed project in the ICT-16-2018 software technology topic.

*Table 38 – Cloud project: RADON*

| | | |
|---|---|---|
| RADON<br>Referenced in H-Cloud deliverable D1.2 | Dates and URL | 1/1/2019 – 30/06/2021<br>*https://cordis.europa.eu/project/id/825040*<br>*https://radon-h2020.eu/* |
| | Title | Rational decomposition and orchestration for serverless computing |
| | Objective | DevOps framework for creating and managing microservices-based applications that can optimally exploit serverless computing technologies |
| | Value to continuum computing | Ambient assisted living use cases<br>Capabilities: Constraint definition language and associated verification tool, continuous testing tool, graphical modelling tool, decomposition tool, defect prediction tool, orchestration |



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| | | |
|---|---|---|
| | | *https://radon-h2020.eu/wp-content/uploads/2020/07/D2.4-Architecture-and-integration-plan-II.pdf* |

### 3.8.3 UNICORE (Cloud project)

UNICORE is a completed project in the ICT-16-2018 software technology topic.

*Table 39 – Cloud project: UNICORE*

| | | |
|---|---|---|
| UNICORE Referenced in H-Cloud deliverable D1.2 | Dates and URL | 1/1/2019 – 31/03/2022<br>*https://cordis.europa.eu/project/id/825377*<br>*https://unicore-project.eu/* |
| | Title | A Common Code Base and Toolkit for Deployment of Applications to Secure and Reliable Virtual Execution Environments |
| | Objective | Common code base and toolkit for deployment of applications to secure and reliable execution environments. |
| | Value to continuum computing | Unikernels (smallest lightweight VMs one can create)<br>*See Unikraft: https://unikraft.org/*<br>Innovation assets: API and library implementation, security and isolation primitives, deterministic execution support, compile toolchain, multi-target support, symbolic verification support, performance optimization tools, orchestration tools integration, module toolchain<br>*https://zenodo.org/record/5059901#.Y9_DRnbMJyw* |

### 3.8.4 Fed4IoT (IoT project)

Fed4IoT is a completed project in the EUJ-01-2018 topic (Advanced technologies (Security/Cloud/IoT/BigData) for a hyper-connected society in the context of Smart City)

*Table 40 – IoT project: Fed4IoT*

| | | |
|---|---|---|
| Fed4IoT Referenced in H-Cloud deliverable D1.2 | Dates and URL | 1/7/2018 – 31/09/2021<br>*https://cordis.europa.eu/project/id/814918*<br>*https://fed4iot.org/* |
| | Title | Federating IoT and cloud infrastructures to provide scalable and interoperable Smart Cities applications, by introducing novel IoT virtualization technologies |
| | Objective | Multilevel IoT interoperability for smart-city, large scale, cross-domain applications<br>Cooperation with Japan |
| | Value to continuum computing | IoT Virtualisation stack, and architecture based on UniKraft<br>*https://fed4iot.org/wp-content/uploads/2020/11/D2.3.pdf* |



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# 4 Towards a Computing Continuum Ecosystem

Influencing the evolution of the computing continuum ecosystem should take into account:

- the wealth of initiatives as listed in [2] (section on community building):
    - MetaOS Projects, H-CLOUD, HUB4CLOUD, SWForum, OPEN DEI, EU-IoT, NGIOT, 5G PPP, GAIA-X, IDSA, 6G-IA, AIOTI, ECSEL, KDT and the future Chips JU, Data Spaces Business Alliance, European Alliance for Processors and Semiconductor Technologies, TransContinuum Initiative, and
    - the joint Unlock CEI and OpenContinuum initiative[4].
- the wealth of reports produced by AIOTI ([3], [4],[5], [6]), BDVA [7], or OpenDei ([8], [9], [10], [11]).

Table 41 lists target stakeholders for a community building [2] that will consist of three phases

- Phase 1 awareness creation and community building (2022)
- Phase 2 community outreach and engagement bootstrap (2023)
- Phase 3 global outreach and retention (2024)

*Table 41 – OpenContinuum Target Stakeholders*

| Target Audience | Sub-groups |
|---|---|
| Cloud-Edge-IoT research projects | Cloud-Edge-IoT funded projects:<br>• HORIZON-CL4-2021-DATA-01-05<br>• HORIZON-CL4-2022-DATA-01-02<br>• HORIZON-CL4-2022-DATA-1-03<br>• Horizon 2020 projects (RIAs & CSAs) |
| Open-source projects and standards communities | Communities and bodies such as CNCF, Eclipse Cloud Development (ECD) Tools, Eclipse IoT and Edge-Native Working Groups, Open Stack, ETSI and other SDOs, relevant projects such as Stand.ICT. Projects such as AERO, OpenCUBE, RISER and Vitamin-V |
| Cloud-Edge-IoT providers | Developers in the Cloud-Edge-IoT landscape; technology providers (big, SMEs and start-ups, to consider all the characteristics, opportunities and barriers). |
| Researchers/Scientists from industry or academia | Researchers (academia and industry); PhD students; Postdoctoral students; Early career researchers; Research Leaders; Top academics. |
| Policy makers | Policy Makers, regulators, and legislators. |

## 4.1 Strategic Approach

Figure 2 shows the intended approach to foster the creation of a computing continuum ecosystem:

- On the left-hand side, OpenContinuum will engage projects with two objectives:
    - Create a taxonomy of computing continuum reference building blocks what will serve for the construction of a computing continuum architecture.
    - Help projects work together towards the availability of implementation enablers (in particular open source enablers).

[4] https://eucloudedgeiot.eu/



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- On the right-hand side, OpenContinuum will engage projects towards
  - The specification of reference architectures based on ISO/IEC JTC1 practice [12] and ISO/IEC/IEEE 42010 [13] so that contribution can be made at standardisation level.

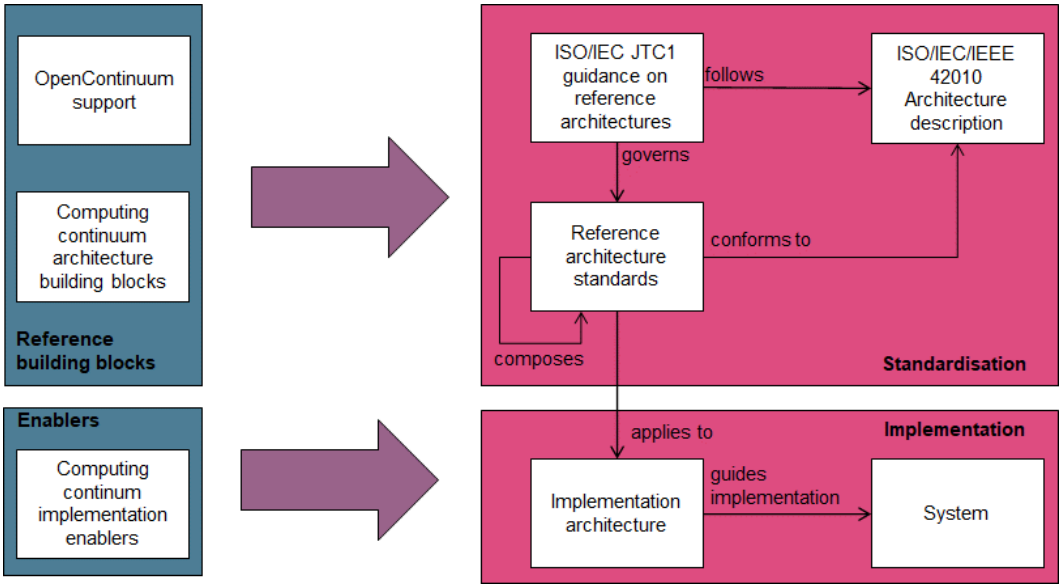


*Figure 2 – OpenContinuum Strategic Approach for Ecosystem Impact*

The proposed approach leverages the following references:

- An interoperability approach as envisioned by [14], [15].
- Alignment with the future IoT reference architecture standard, [16], and an approach based on patterns (as in [17])j
- Alignment with the future Digital Twin reference architecture [18], and
- Support for domain specific standards such as RAMI for smart manufacturing [19] or SGAM for energy [20].

## 4.2 Continuum Computing Capabilities

The Edge Computing Consortium has described the points of collaboration[5] between edge computing and cloud computing as follows:

| Point of collaboration | Edge Computing | Cloud Computing |
|---|---|---|
| Network | Data aggregation (time sensitive networking[6], OPC unified architecture[7]) | Data analysis |
| Service | Agent | Service orchestration |
| Application | Micro applications | Lifecycle management of applications |
| Intelligence | Distributed reasoning | Centralized training |

[5] http://en.ecconsortium.net/Uploads/file/20180328/1522232376480704.pdf

[6] https://en.wikipedia.org/wiki/Time-Sensitive_Networking

[7] https://opcfoundation.org/about/opc-technologies/opc-ua/



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An initial taxonomy has been proposed by [21]. as seen is Figure 3:

- Integration building blocks,
- Brokering building blocks,
- Application building blocks,
- Orchestration building blocks, and
- Trust and performance building blocks.

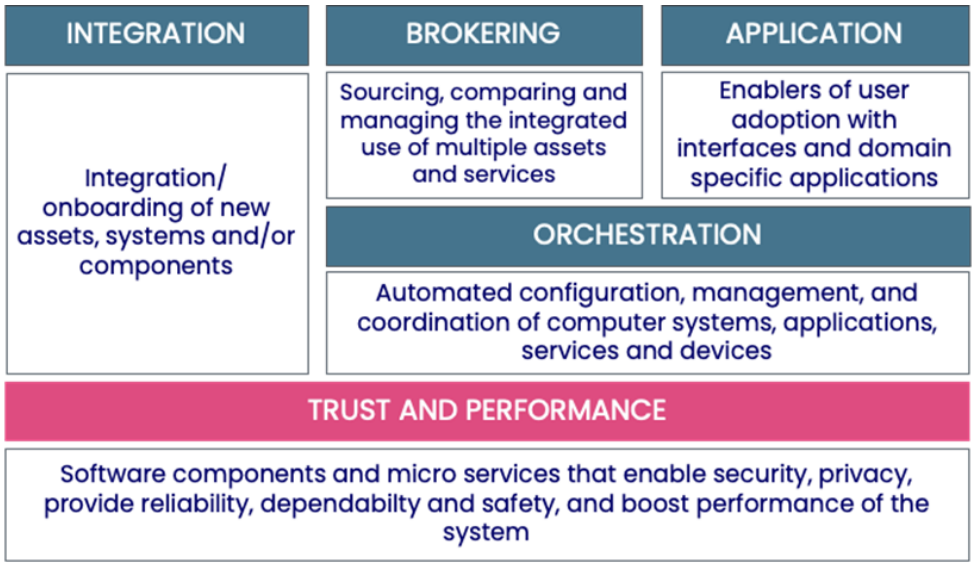


*Figure 3 – Proposed Reference Building Blocks*

Figure 4 shows the enablers that have been provided by projects [21].

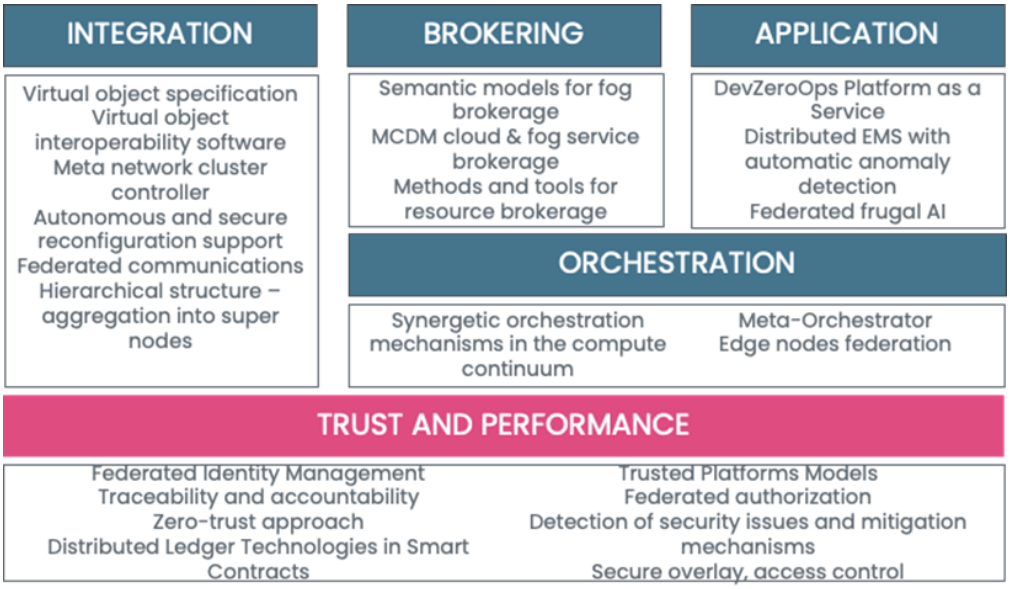


*Figure 4 – Enablers proposed by supported projects*


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# 5 Conclusion: from Innovation Vectors to Impact Vectors

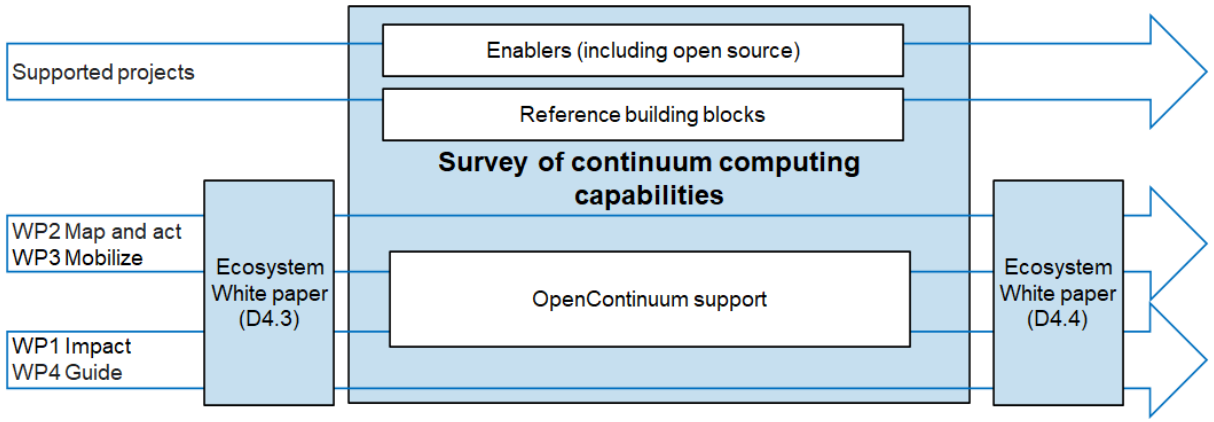


*Figure 5 – OpenContinuum Engagement Approach*

Figure 5 shows the proposed approach:

- OpenContinuum will engage innovation vectors, represented by projects (role of WP3 - Mobilization)
- OpenContinuum will help projects construct, identify impact vectors, or common building blocks and implementation enablers (role of WP2 – Map and act)
- OpenContinuum will assist MetaOS projects towards open source development plans, and projects towards alignment with standards (role of WP1 Impact)



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