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Circular and Dynamic Manufacturing Supply Chain Orchestration and OptimiSation

D4.1 Enablers of Local I4.0 Data Layers			
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Catalog

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Abbreviations

Acronym	Description
BPM	Business Process Model
CMRA	Circular manufacturing Reference Architecture
EBSI	European Blockchain Services Infrastructure
EXD	Experiment Demonstrator (from the Open Calls)
LCA	Life Cycle Assessment
MSME	Manufacturing Small and Medium Enterprises
NGSI-LD	Next Generation Service Interfaces - Linked Data
PEP	Policy Enforcement Point
RAMP	Robotics and Automation MarketPlace
SDMs	Smart Data models
T4.1	CIRCULOOS Task 4.1- Local I4.0 Data Layers
WP2	CIRCULOOS Work Package 2 - Requirements, User Stories and Architecture

Executive Summary

This report summarises the approach, and results (executable code, functionality) reached under T4.1 in the first year of the project (M12). The task develops the functionality for enabling supply chain participants to produce/consume compatible and comparable data which is suitable not only to optimise local processes but also to accelerate the integration/interoperability features that aim to support data sharing beyond the boundaries of their organizations. The CIRCULOOS approach to this challenge consists of connecting the heterogeneous data sources of supply chain participants to an agent-based data collection environment which i) safely handles the custom interfaces of the data source and its associated asset, ii) when necessary, applies basic data transformation (conversion between data types and elementary data curation) and, iii) handles the bidirectional communications between the local data source and remote endpoints.

The implementation presented in this report builds on the foundational framework that CIRCULOOS is developing in WP2. The CIRCULOOS framework already accounts for the preliminary release of the open Circular manufacturing Reference Architecture (CMRA) and a series of architecture blueprints which include the scenarios for the local data platform. Most of the base building blocks included in the platform blueprints are now available and the objective of task 4.1 is to keep evolving a framework of enablers to i) facilitate the composition, configuration and maintenance of the local data platforms in production and ii) enable the seamless integration of the CIRCULOOS local framework for sustainability and circularity along with the local data platforms in vertical solutions. An overview of the current implementation, convenient link to the source code and its documentation, and a basic description of an executable demo of the platform are provided in this report as a reference to those technical profiles which may be interested in a hands-on experience. The CIRCULOOS data layer provisions the required data to the respective CIRCULOOS tools towards the realization of the idea of building *new* supply chains. These supply chains are built to achieve minimal environmental footprint (see Supply Chain Optimization – D3.7), based on the assessment made on the Life Cycle Assessment of production processes and products (D3.5) and the Orchestration of these new Supply Chains (D3.1).

1 Introduction

1.1 Project Introduction

The overall vision of CIRCULOOS is to deliver the tools to enable MSMEs become full members of the Circular Manufacturing value chain. These tools orchestrate and continuously optimise the supply-chain end-to-end and integrate planning and execution monitoring to enable transparent and on-time communication. Combining these with direct calculation of the product sustainability and circularity profile, for both internal and external partners, this environment will enable them to configure and execute disruptive circular manufacturing processes for sustainable production that covers the entire life cycle of products; either by recovering the value of product that ended-up as waste or from recycled and remanufactured products. To achieve such objective the project aims to deploy:

- Circular end-to-end supply chain orchestration for collaborative workflows which incorporates planning and execution metrics and integrates advanced and multimodal visualisation and analytics. The visualisation is delivered by comprehensive Digital Twins of the supply chains formulated, the factory processes and product design phases.
- Supply Chain Optimisation that monitors the global (across the supply chain) and local (within the factory) processes and execution, inputs and outputs and configuration parameters, to enable data-driven AI decision making, this way supporting continuous optimisation of targeted and measured performance and sustainability parameters.
- Dynamic Sustainability Assessment functionalities that investigate alternative supply-chain scenarios (varying in terms of materials used, processing technologies, suppliers involved and/or activated circular economy practices) in place of the existing schemes, quickly measuring their performance in terms of environmental sustainability and circular economy profile.
- Supply Chain Data Spaces for seamless, multi-level data flow across the supply chain partners, supporting the reuse of materials in novel products, the extension of the life-cycle of finished products (remanufacturing), and data-driven decisions for collaboration of parties offering matching services in the most dynamic and efficient way.
- Cybersecure and trustworthy data sharing across the supply chain by employing a distributed, trusted and efficient Identity and Access management system, that together with the associated trust framework will coordinate the identities of all IoT objects and ensure trustworthy data sharing among its members, aligned with the trust framework that is being implemented in EBSI.
- CM specific tools for the automatic recognition of recyclable parts by modern Machine Vision tools and Advanced Robotics, to enable optimised flows in the selection process.
- Novel circular business processes will be demonstrated supporting reusing, reducing, and recycling material in production and consumption systems. The new collaborative production models will provide quantifiable results on the sustainability increase across the supply chain, in terms of efficient use of raw materials, of by-products, of waste and energy and of emissions reduction. CIRCULOOS leverages the above with the RAMP integrated innovation IOT platform and the European network around it to deliver a CM ecosystem and platform for Manufacturing SMEs.

- Skills upskilling and reskilling will be provided in RAMP and through online courses, webinars, and best practice guides and success stories based on the pilots and Experiments for Demonstration (EXDs).

1.2 Deliverable Purpose

The deliverable provides a description of the results of Task 4.1 and the links to the online repositories containing the source code along with convenient guidelines to execute an illustrative demo.

The material presented in this deliverable includes:

- A brief overview of the CIRCULOOS technical approach, reference architecture, and base platform building blocks
- An introduction to the structure and main features of the local data platform developed for the collection of information of regular production and by-products from the manufacturers
- A summary of the contents in the local platform repository (codebase and executable demo), which is available at: https://github.com/european-dynamics-rnd/circuloos-data-platform
- Last but not least, a brief closing chapter covers the conclusions and next steps associated with the contents discussed in this deliverable

2 Enablers of Local I4.0 Data Layers

The main role of Local I4.0 Data Layers is to abstract the heterogeneity of the custom data formats and multiple communication patterns used by the heterogeneous industrial assets of a company (e.g., product and material models, sensors, field devices, workstations, information systems...). To do so, the I4.0 approach is to connect each of these assets to interoperable I4.0 Agents which are mainly responsible for handling bidirectional communications between native asset interfaces and a common data environment in which all the agents produce/consume data using the same interfaces and harmonised data formats. In CIRCULOOS, agent interfaces rely on the NGSI-LD standard to ensure the compatibility of their interfaces and the FIWARE Context Broker technology is the software component in charge of implementing the common data environment that enables data exchange between NGSI-LD agents. Finally, agent interoperability is unachievable without the use of well-structured data models and shared semantics for the exchanged data payloads. CIRCULOOS relies on the Smart Data Models program as its reference agile standardisation framework to achieve such harmonisation of data payloads.

2.1 Reference Architecture and Base Building Block Implementations

The deliverable “D2.2 Circular Manufacturing Reference Architecture Specification (CMRA)” describes an architecture framework and a series of building blocks that are essential to build circular manufacturing data platforms. Besides the building blocks for data acquisition and data brokering, additional building blocks encapsulate the necessary features to accelerate circular manufacturing chains by seamlessly integrating orchestration, sustainability assessment, and optimization capabilities. Often, reference architecture specifications lack actual software implementations which can meet the requirements specified for its building blocks. This is not the case in CIRCULOOS. Several IoT Agents already exist in the FIWARE and RAMP catalogues to seamlessly integrate NGSI with OPC UA, MQTT, HTTP, ROS 2, RS232 and many other native asset communications in the I4.0 data layer. There are multiple options available for open-source context broker implementations. A great collection of existing data connectors brings the integration of CIRCULOOS local data layers with most of the relevant databases in the market as an off-the-shelf feature. Furthermore, the FIWARE technology already contributes a security stack that can efficiently implement local identity and access management.

However, the instantiation, combination and integration of base building blocks implementations is often insufficient to meet the demanding requirements of real-world cases. Thus, the focus of Task 4.1 in this period was on

1. maximising the reuse of existing building blocks (even if they do require some basic tailoring to perform in the target use case) to build up a minimum viable platform
2. describing a meaningful and expressive proof-of-concept, inspired in the CIRCULOOS goal and hosted pilots, that could serve as a reference for replication in diverse real-world use cases
3. implementing a CIRCULOOS Local Data Platform which extends the minimum viable platform to offer a functional solution to the envisioned proof-of-concept along with an easy-to-run demo.

2.2 The CIRCULOOS Local Data Platform

The data platform comprises of two main elements: (a) the 'agent' deployed at the data-collection points, i.e. the manufacturer's premises/ shopfloor and (b) the server-side deployed at the premises of European Dynamics, which hosts the infrastructure for the persistent storage of this data and its connection to the RAMP Marketplace. An 'agent' is a software component that bridges IoT devices and the CIRCULOOS Data Platform by translating device-specific protocols into the standard NGSI -LD format. It enables seamless communication between IoT devices and Orion-LD context broker, allowing data exchange and management in smart applications. The functionality of the data platform, the connection requirements as well as an executable demo are available at the online documentation and briefly described in this chapter.

2.2.1 Implementation Overview

The implementation of the CIRCULOOS Platform is based upon the RAMP-IIoT-LD. It adopts existing open-source components following the NGSI-LD standard and FIWARE Context Broker as core enablers for interoperability. Furthermore, a series of open-source tools (described on Section 2.2.2 Software Enablers) have been integrated along with some custom developments to achieve a fully functional prototype. The main goal of the current release is to serve as a reusable platform template which is equipped with minimal configurations to facilitate a smooth startup of any pilot or upcoming deployemtn of the experiments to be selected. Finally, a functional demo has been developed and conveniently documented to help developers and administrators understand and get familiar with the most relevant platform features. The usability of the platform have been tested and performed initial integration by CIRCULOOS partners: SUPSI (GRETA), CUT (SCDT) and leather pilot. Further tested will be performed with rest of CIRCULLOS pilots and all EXD participants.

The codebase of the CIRCULOOS data collection is publicly available as a Github Repository: https://github.com/european-dynamics-rnd/circuloos-data-platform.

2.2.2 Software Enablers

The following components from the catalogue of FIWARE generic enablers are included in the platform:

- Orion-LD as Context Broker.
- Mintaka as NGSI-LD temporal retrieval API (OpenAPI Specifications).
- Keycloak as single sign-on with identity and access management.
- Kong as PEP (Policy Enforcement Point) proxy for Orion-LD and Mintaka.
- Hyperledger Besu as the Blokchain client software for Alastria Besu Network.

Other platform components that have been integrated with FIWARE Generic Enablers to implement a fully functional platform are:

- Apache Superset as open source enabling tool for data exploration and visualization
- timescale-db as an open source time series database

- Custom Service I - Python csv to NGSI-LD, an emerging NGSI-LD agent that enables the seamless integration of local csv formatted data into the CIRCULOOS platform
- Custom Service II -Outline of 2D object to NGSI-LD,, an emerging NGSI-LD agent that enables the seamless integration of an 2D object (ie fabric or leather offcuts) into the CIRCULOOS platform
- Custom Service III - CIRCULOOS registration to entities, an enabling feature to implement the NGSI-LD federation scheme without compromising the platform security mechanisms

2.2.3 Platform Features Enabled for this Release (Implementation Details)

The data platform has been implemented and released for access to the manufacturing end-users to enable them feed data, so that it can be ingested - as a first step - in RAMP. The data formally modelled as NGSI-LD entities, corresponds to descriptions of volumes/ areas/ mass and physical properties for the types of material handled by the pilot end-users. These material descriptions are either publications of by-products/ waste produced by a manufacturer that can be used by another, or requests for recyclable material by a manufacturer. These requests for material (production resources) or publications of byproducts are made through RAMP so that the community engaged in the circular practices can start to gain some momentum. At a later phase of the CIRCULOOS project, the types of data handled by the platform may extend to indicators of the production process. These indicators may be signals from sensors installed on the shopfloor and will be used to show the status of newly configured supply chains.

The design of the data platform allows for the connection of manufacturing end-users with the minimal effort and provides different options for data privacy. There are currently two implementation options available: (a) one that pushes the data, that the end-user makes available to the data platform directly or (b) another scheme (federated) that has an additional phase of configuration so that end-users can select at a later stage which data they want to push to the data platform. So, the end-users have essentially two options when it comes to data sovereignty: (a) either preselect which data they want to push to the data platform and connect these data sources to the platform or (b) connect the entire dataset and discriminate on which subsets to publish at a later point. Both functions have been implemented in the open-source software described below, with a comprehensive set of instructions of use (documentation) for the manufacturing end-users and a sandbox environment that hosts the entire platform - for purposes of training and familiarisation with the technologies used.

The provided version of the platform, available on GitHub, includes comprehensive instructions to help users get started with the CIRCULOOS platform. The primary objective is to create a sandbox environment for partners and participants in open calls, enabling them to familiarise themselves with the platform, test its functionalities, and extend its features to meet their specific needs. By offering external components and source code for the CIRCULOOS platform, the aim is to increase transparency and foster trust among participants.

A key part of CIRCULOOS vision is to offer streamlined and accessible insights into the inner workings of the CIRCULOOS platform. To support this, a detailed set of instructions has been prepared and published. All custom components have been dockerized to ensure a consistent, portable, and scalable environment for deployment. Docker provides several advantages, such as simplified dependency management, a more efficient deployment process, rapid scalability, and seamless integration across diverse environments. Furthermore, Docker enhances resource efficiency and isolation, ensuring that each component operates reliably and independently of the underlying infrastructure.

The demo serves as a vital tool for users to explore the capabilities of the CIRCULOOS platform in a controlled environment. It allows users to evaluate its architecture, test use cases, and gain hands-on experience with the platform's core features. This practical exposure will help participants better understand the platform's potential, identify how it can be tailored to their specific needs, and streamline future integrations.

To begin working with the demo, users will need access to a computer or virtual machine running any Linux distribution (preferably a Debian-based derivative), along with basic knowledge of Linux and Docker. An initialization script has been prepared to download and build the necessary components. Basic examples have been included to help users become familiar with the platform, along with links to tutorials and other resources to expand their understanding of the various components used to develop the CIRCULOOS platform.

Before manufacturing end-users can transmit data from the CIRCULOOS data platform, they must first acquire credentials through European Dynamics. End-users have two options for sending data to the platform:

1. Direct Data Submission (Option 1): Users can submit data in NGSI-LD JSON format directly to the Orion-LD Context Broker. In this case, the user must implement a mechanism to obtain an authentication token from the CIRCULOOS Keycloak system and include it in the NGSI-LD JSON request.
2. Federated Data Submission (Option 2): Alternatively, data can be sent through the NGSI-LD Federation scheme. Here, the data is transmitted to a local or shop-floor Orion-LD Context Broker, which then forwards the data to the central CIRCULOOS Orion-LD. This federated approach provides an additional layer of security and anonymity for data transmission.

Figure 1 illustrates the primary architectural components of the CIRCULOOS Data Platform, highlighting both options:

- (a) Direct data submission to the central Orion Context Broker (depicted in the top-left boxes labelled 'partner PC').
- (b) Federated data submission via local Context Brokers (shown in the lower-left box labelled 'Local Pilot').

The federated scheme enhances security, while direct connections to the central Orion Context Broker provide simpler, direct data transmission pathways. This platform is hosted on both the European Dynamics servers and it is in the process of deployment to the pilot locations of end-users, ensuring seamless connectivity between the two environment.

To reduce the technological barrier for end-users, an open-source IoT Agent was developed. This agent facilitates the translation of CSV files into NGSI-LD JSON format and includes the necessary authentication mechanisms and implements the direct data submission process. The IoT Agent can operate as a standalone application or be integrated into the local or shop-floor installations of the CIRCULOOS platform. Following a testing period (tested by the EXD), the IoT Agent will be incorporated into RAMP-IIoT-LD platform as an enabler for the MSME entering into circular business.

Blockchain platform allows to register tamper-proof evidence of the database information, that can be easily verified. The way to register data evidence and query the previously registered evidences, is

through a REST API (Representational State Transfer data format for an Application Programming Interface).

REST APIs are the most standard approach to connect web applications in a frictionless way, ensuring functional compatibility, abstracting the programing language used to develop the different connected applications. In this case, thanks to the Blockchain platform's REST API, the data platform can periodically send the tamper-proof evidence to register to the Blockchain. Again, thanks to the Blockchain platform's REST API, the tamper-proof evidence can be checked and verified at any time. This is very useful, especially for auditing processes and to create a trust ecosystem across the different participants.

The RAMP Marketplace is hosted within the European Dynamics infrastructure (referred to as ED) and can access data from either the central data storage or through the Kong Proxy component, part of the FIWARE ecosystem, for enhanced isolation.

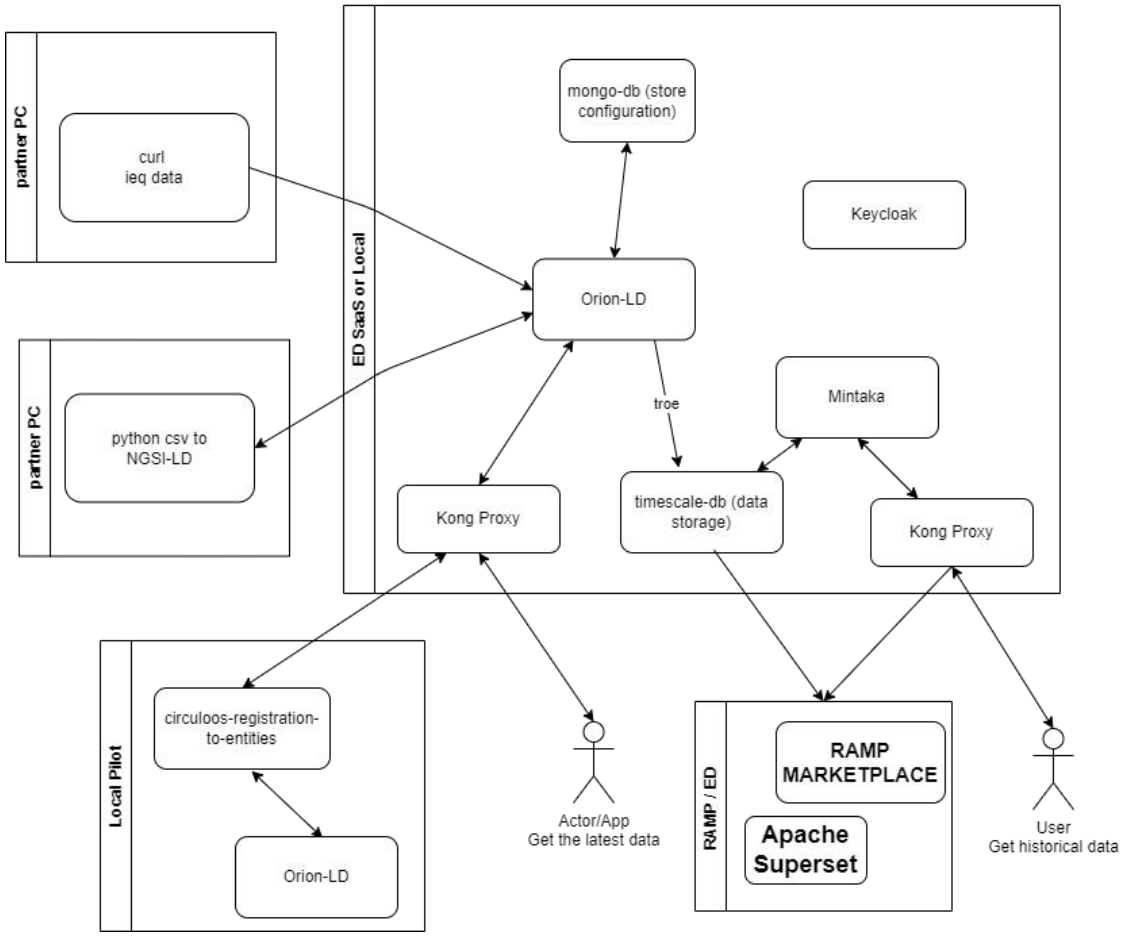

Figure 1 Architecture diagram and main software components in the CIRCULOOS Data Platform

2.2.4 Demo

The software implementation of the data collection platform has been deployed at the premises of European Dynamics and has been integrated to the RAMP Marketplace. The VM specification and configuration option were based on previous implementations of the RAMP-IIoT-LD platform (BetterFactory No 951813) where the CIRCULOOS Data platform is based. Manufacturing end-users have

deployed the corresponding software component (python converter to NGSI-LD at the left hand-side of Figure 1) on premises that allows them to periodically feed data to the data platform. This data represents information about their scheduled production in the form of either estimated volume/ mass of byproducts from future production or a request for (raw) material to cover their production needs. This information is directly consumed by RAMP, which creates a corresponding post on the company's digital space, which may be publicly visible or restricted to a subset of the RAMP users.

The CIRCULOOS platform publishes, as a first step, material resources to the RAMP Marketplace to motivate the idea of a Marketplace of recycled/ repurposed goods. In a future evolution of the Circuloos idea, this information will be used to help manufacturing end-users coordinate their production schedules by forming dynamic supply chains. The new supply chains will be formed based on the availability of recyclable/ reusable material by other members of the Circuloos idea. The implementation of this next step will require the integration of the Supply Chain Optimization Tool and the Greta platform (LCA tool) to this data platform and the RAMP Marketplace.

The participants of EXD will need to provide their data into a NGSI-LD JSON compatible format either by the use of the open-source IoT Agents developed in the contexts of CIRCULOOS, IoT Agents by FIWARE or their own software components.

3 Conclusion and Next Steps

The work carried out under Task 4.1 during the first year (M12) has successfully laid the groundwork for enabling supply chain participants to produce and consume compatible and comparable data. This data is essential not only for optimising local processes but also for accelerating integration and interoperability across organisational boundaries.

The implementation discussed in this report builds upon the foundational work established in WP2, particularly the preliminary release of the open Circular Manufacturing Reference Architecture (CMRA) and the associated architecture blueprints. With most of the fundamental building blocks for the local data platform now in place, the objectives of Task 4.1 have been to further refine these enablers to support the seamless composition, configuration, and maintenance of local data platforms.

The report also provides a detailed overview of the current implementation, including insights into the available source code, documentation, and a basic executable demo of the platform. These resources serve as a valuable reference for technical stakeholders interested in exploring or experimenting with the platform's capabilities.

Looking ahead, the short-term roadmap focuses on refining and maturing the existing implementation to enhance stability and functionality. The mid- to long-term roadmap envisions several key milestones:

- **Finalizing tool integration**: Complete the connection of CIRCULOOS project tools, such as ScOpt, Greta (LCA tool), Blockchain, Digital Twin, and Process Orchestrator, which are essential for optimising supply chains based on their environmental footprint.
- **Traffic monitoring and analytics**: Establish tools to monitor and analyse data flows across the platform to ensure efficient and secure operations.
- **Leveraging platform usage statistics**: Utilise platform usage data as part of a broader promotional campaign to showcase the CIRCULOOS initiative, including through project dissemination activities and the RAMP platform.
- **Onboarding new manufacturing entities**: Attract and integrate additional manufacturers through the Open Calls to expand the platform's user base and impact.

- Integrating new Blockchain platform functionalities: Blockchain platform also allow to tokenize different aspects of the CIRCULOOS ecosystem, like contractual agreements between parties (currently in progress) and tokenized payments inside the platform. We are also working in self-sovereign digital identity (SSI) integration with Blockchain platform.

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