



Circular and Dynamic Manufacturing Supply Chain Orchestration and Optimisation

D2.2 CMRA Specification			
Report Identifier:	D2.2		
Work-package:	WP2	Task:	T2.2
Responsible Partner:	FIWARE Foundation e.V. (FIW)	Version Number:	1.0
Due Date	31/05/2024	Document Date:	17/06/2024
Distribution Security:	PUB	Deliverable Type:	R
Keywords:	CMRA, Circularity, Manufacturing, Architecture, Standard		
Project website: https://circuloos.eu/			

Document History

Version	Issue Date	Content & Changes	Author
0.1	03/04/2024	Document created	Francisco Melendez
0.2	03/06/2024	Document sent for review	Francisco Melendez
0.3	10/06/2024	Document reviewed	Elia Ruiz Giuseppe Landolfi
0.4	10/06/2024	Document reviewed	Anett Dobos
0.5	11/06/2024	Reviews are combined	Francisco Melendez
0.6	11/06/2024	Sent for Quality Assurance	Themis Kolyvas
1.0	17/06/2024	Quality Assurance and Submission	Anastasia Garbi

Quality Control

	Name	Organisation	Date
Editor	Francisco Melendez	FIW	03/06/2024
Peer review 1	Elia Ruiz Giuseppe Landolfi	SUPSI	10/06/2024
Peer review 2	Anett Dobos	INN	10/06/2024
Authorised by (Technical Coordinator)	Themis Kolyvas	ED	14/06/2024
Authorised by (Quality Manager)	Themis Kolyvas	ED	14/06/2024
Submitted by (Project Coordinator)	Anastasia Garbi	ED	17/06/2024

Legal Disclaimer

CIRCULOOS is an EU project funded by the Horizon Europe (HORIZON) research and innovation programme under grant agreement No. 101092295. The information and views set out in this deliverable are those of the author(s) and do not necessarily reflect the official opinion of the European Union. The information in this document is provided “as is”, and no guarantee or warranty is given that the information is fit for any specific purpose. Neither the European Union institutions and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information contained therein. The CIRCULOOS Consortium members shall have no liability for damages of any kind including without limitation direct, special, indirect, or consequential damages that may result from the use of these materials subject to any liability which is mandatory due to applicable law.

Copyright notice

© Copyright by the CIRCULOOS Consortium

This document contains information that is protected by copyright. All Rights Reserved. No part of this work covered by copyright hereon may be reproduced or used in any form or by any means without the permission of the copyright holders.

Table of Contents

1 Executive Summary	10
1.1 Deliverable Purpose	10
1.2 Background	10
1.3 Vision	12
1.4 Approach	13
2 The Circular Manufacturing Reference Architecture	14
2.1 Stakeholders Definition	14
2.2 Problem Description and Reference Scenarios	16
2.3 Target Capabilities	17
2.4 Design Principles	19
2.5 Assumptions	21
2.6 Prioritized Concerns and Architectural Viewpoints	22
2.6.1 Concerns and Viewpoints on Enabling Features for Federated Supply Chains	22
2.6.2 Concerns and Viewpoints on Supply Chain Optimisation Capabilities	23
2.6.3 Supply Chain Process Orchestration and Execution Capabilities	23
2.6.4 Stakeholder Engagement Capabilities	23
2.6.5 Reusable tools for MSMEs vertical solution development	23
3 A Reference Implementation: The CIRCULOOS Data Platform	24
3.1 Overall Context	24
3.1.1 The CIRCULOOS Project	24
3.1.2 Target Capabilities and Prioritized Platform Objectives	25
3.1.3 Overview of CIRCULOOS Industrial Pilot Requirements	27
3.2 CIRCULOOS Platform Description (Design Phase)	29
3.2.1 Generic Platform Capabilities and Software Enablers	29
3.2.1.1 Local Data Platform	31
3.2.1.2 Data Sharing Framework	32
3.2.1.3 Blockchain-based services for trustworthy and secure data sharing	36
3.2.2 Circular Manufacturing Capabilities and Software Enablers	37
3.2.2.1 Stakeholder Engagement and Collaboration (RAMP)	37

3.2.2.2 Supply Chain Process Orchestration and Execution Tool (SCPO Tool)	38
3.2.2.3 Sustainability Assessment (GRETA Tool)	39
3.2.2.4 Supply Chain Digital Twin (SCDT Tool)	39
3.2.2.5 Supply Chain Optimization (SCOPT Tool)	39
3.2.2.6 CV-based system for composition detection	40
4 Conclusions	42
4.1 Design Decisions and Trade-offs	42
4.2 Implications for related Circular Manufacturing Projects	42
4.3 Future Directions	42

List of Figures

Figure 1 The Ellen MacArthur Circular Economy Systems Diagram. The focus of the CMRA is on the set of cycles often referred to as R-Strategies (highlighted by red boxes in the picture).....	11
Figure 2 The CMRA Capability Map	18
Figure 3 Direct Supply Chain represent linear supply chain models while the reverse flows are circularity enablers implemented by R-strategies.....	25
Figure 4 Top Level View of the CIRCULOOS Platform (Global + Local Data Layers).....	31
Figure 5 Detailed View of a Local Data Layer (Vertical Solution of a single Supply Chain Participant).....	31
Figure 6 Context Source Registration	34
Figure 7 CIRCULOOS Platform main components.....	35
Other Figures (“Appendix A - CIRCULOOS Platform Demo”)	
- Figure A1. UI for outline extraction from 2D images.....	44
35	
- Figure A2. CSV to Orion-LD agent feature (Snapshot of the Web interface).....	45
- Figure A3. Extract of an input file (csv format).....	45
- Figure A4. Part of the generated NGSI-LD JSON file.....	46

List of Tables

Table 1 CMRA Reference Scenarios..... 16

Table 2 CMRA Capability Categories17

Table 3 Assumptions made for feasible CMRA based data platform designs..... 21

Abbreviations

Acronym	Description
AAS	Asset Administration Shell
API	Application Programming Interface
BPMN	Business Process Model and Notation
CMRA	Circular Manufacturing Reference Architecture
CPS	Cyber-Physical System
CRUD	Create, Read, Update, Delete operations
DIDs	Decentralized Identifiers
IAM	Identity and Access Management
IT	Information Technology
IoT	Internet of Things
LCA	Life Cycle Assessment
MSMEs	Manufacturing Small and Medium sized Enterprises
MPMS	Manufacturing Process Orchestration
MVP	Minimum Viable Product
NGSI-LD	Next Generation Service Interfaces - Linked Data
OEE	Overall equipment effectiveness
PEP	Policy Enforcement Point
PoC	Proof of Concept
RAMI4.0	Reference Architectural Model Industrie 4.0
RAMP	Robotics and Automation Marketplace
RBAC	Role-based access control
SCDT	Supply Chain Digital Twin Tool
SCPO	Supply Chain Process Orchestration and Execution Tool
VC	Verifiable Credentials
VP	Verifiable Presentations

1 Executive Summary

1.1 Deliverable Purpose

This deliverable documents the first iteration carried out within the CIRCULOOS Project to design an open and reusable reference architecture for more circular and sustainable supply chains in the manufacturing sector. The main purpose of the proposed Circular Manufacturing Reference Architecture (CMRA) is to contribute with an open reference model that accelerates the creation of innovative solutions to enhance the sustainability, resilience, and circularity of existing manufacturing supply chains as well as to ease, foster and promote the creation of new ones which embrace circularity practices at their very early stages. Tailored for both small to medium-sized manufacturing enterprises (MSMEs) and large manufacturers, major emphasis of the CMRA design is put on enabling the design of effective solutions to reduce waste, streamline resource utilization, and champion sustainability across all facets of the supply chain within intricate manufacturing ecosystems¹. Aspects like reusability, modularity, portability and scalability will be driving the design process, always considering security, trust, and privacy preserving aspects as essential enabling pillars of successful designs. The document is structured in two main parts. The first part elaborates on the main principles and abstract design aspects of the CMR. In turn, the second part focuses on the ongoing work towards an open reference implementation of a CMRA based platform which is being carried out in the context of the [CIRCULOOS](#) project.

1.2 Background

The CMRA builds on the Circular Economy Action Plan² and Ellen MacArthur Circular Economy Framework³ as core conceptual circular economy frameworks, which serve as a compass to the purpose and goals of convenient design and specification activities for a reference architecture for circular manufacturing supply chains. In line with this, the alignment of manufacturing supply chains with strategic goals of the European Green Deal promoted by the CMRA will not be the result of reconfiguration of production processes, but rather of the inclusiveness of the involved actors. The ultimate goal is to accelerate innovative models which are *“based on a closer relationship with customers, mass customisation, the sharing and collaborative economy, and powered by digital technologies, such as the internet of things, big data, blockchain and artificial intelligence”*⁴. That is, circularity means for today’s economies data-driven collaborative production models. Yet, data is simply the means for digital technologies to timely communicate information from-and-to actors when ‘change’ is about to happen. It is ‘change’ that triggers the reconfiguration of the production models and this is instigated by the actors themselves. Putting in place the means to prevent, and in the worst case absorb, the negative impact of such changes while maximizing the sustainability and resilience of manufacturing supply chains is the great challenge to be addressed.

¹ The CMRA focuses particularly on accelerating systems and supply chain models which aim to maximize the effectiveness and impact of the R-Strategies suggested by the [Circular Economy Systems Diagram developed by the Ellen MacArthur Foundation](#): Recycle, Remanufacture, Refurbish, Reuse, Redistribute

² <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN>

³ <https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview>

⁴ Extract from the previously cited *Circular Economy Action Plan*

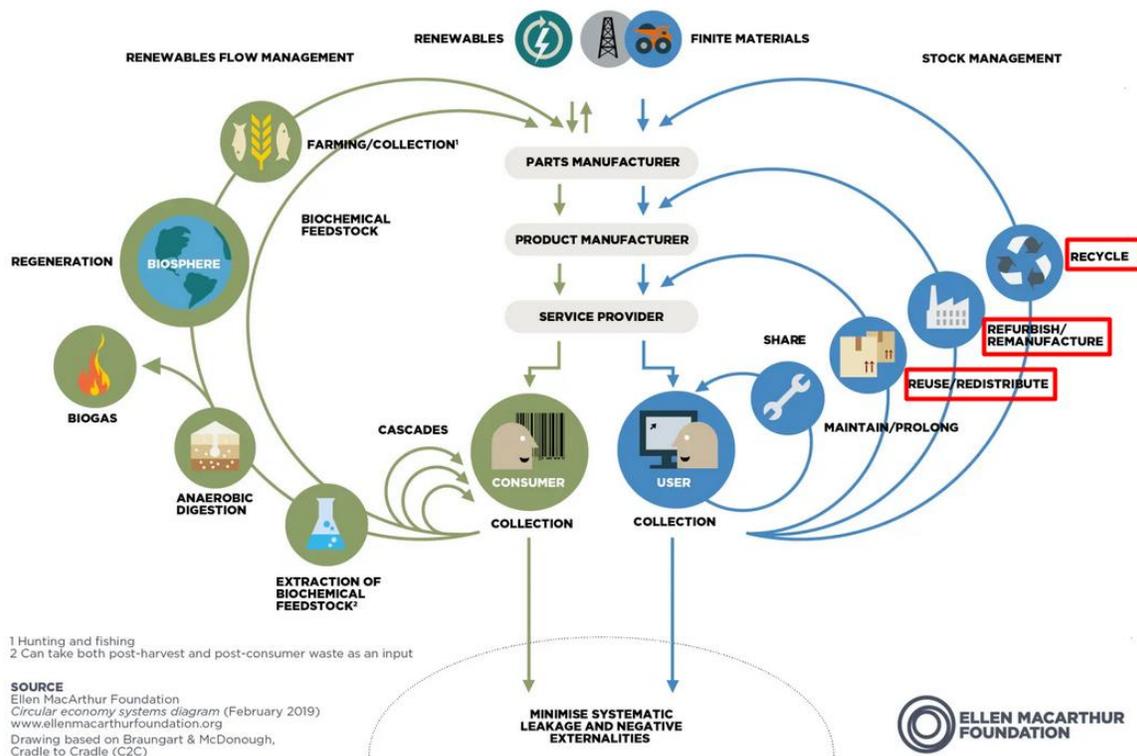


Figure 1 The Ellen MacArthur Circular Economy Systems Diagram. The focus of the CMRA is on the set of cycles often referred to as R-Strategies (highlighted by red boxes in the picture)

Since data economy and digitization are essential enabling pillars to the circular economy and circular manufacturing supply chains, data centrality emerges also as a central concern to the CMRA. Thus, along with the aforementioned circularity principles and frameworks, the CMRA builds on the Reference Architectural Model for Industrie 4.0 (RAMI4.0) as a core enabling framework. In line with this, the previous work carried out in a series of European Projects on smart manufacturing, which has led to the creation of the RAMP IIoT⁵ framework architecture, will be extended to meet the new requirements for circular manufacturing. Particular emphasis will be put on highly detailed specifications and open implementations of reference building blocks for Cybersecurity and Trustworthy Data Sharing. Besides the specifications, the open implementation of these blocks and their integration model for smart manufacturing supply chain solutions is also considered. A digital twin based approach will be followed, also building on existing reference open standards such as the FIWARE Digital Twins⁶ and Asset Administration Shell (AAS)⁷ frameworks.

⁵ <https://ramp.eu/#/learn-about/access-the-ramp-iiot>

⁶ https://www.fiware.org/wp-content/uploads/FF_PositionPaper_FIWARE4DigitalTwins.pdf

⁷ <https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/AAS-ReadingGuide202201.html>

1.3 Vision

“A transition to a circular economy – one where greater efficiency is achieved by closing, extending and narrowing material loops – can play a key role in decoupling economic growth from environmental degradation by greatly reducing the need for resource extraction and use of energy inputs.” <https://www.resourcepanel.org/reports/sustainable-trade-resources>

The CMRA model aims to accelerate a vision in which manufacturers are equipped with the necessary tools to embrace and champion sustainable production practices, in line with the statement above, and throughout the entire lifecycle of products. This encompasses enabling manufacturing supply chain ecosystems which are hyper connected, benefit from trustworthy data sharing, and have timely and cost-effective access to advanced ICT features enabling the integration, orchestration, sustainability assessment, and optimization of their supply chains. The horizon for this vision considers empowered manufacturers which benefit from smooth collaborative processes at every stage in the product life cycle, from resource acquisition to the creation of subassemblies, kits, and final products, culminating in their reincorporation as supply chain resources (not necessarily in the same supply chain they originate from) while keeping loops as short as possible.

The scope for prioritizing design aspects for a circular manufacturing reference architecture that aims to accelerate the realization of the aforementioned vision spans a vast landscape. In the particular context of the proposed CMRA, the EU call topic [I4MS2](#)⁸ and, more specifically, one of the awarded innovation actions within that program ([N° 101092295 - CIRCULOOS](#)⁹) are the major driving elements which bring the requirements to prioritize design goals and decisions. After a detailed analysis of the mandates and requirements set by such initiatives, the following list of prioritized concerns and architecture viewpoints is considered of highest priority for this first iteration on the CMRA specification¹⁰:

- Core Enabling Features for Federated Circular Supply Chains
- Supply Chain Optimisation Capabilities
- Supply Chain Process Orchestration and Execution Capabilities
- Stakeholder Engagement Capabilities
- Reusable tools for MSMEs vertical solution development

⁸ EU Topic: HORIZON-CL4-2022-TWIN-TRANSITION-01-06: ICT Innovation for Manufacturing Sustainability in SMEs (I4MS2) (Made in Europe Partnership) (IA)

⁹ Innovation Action: 101092295 - CIRCULOOS Circular and Dynamic Manufacturing Supply Chain Orchestration and Optimisation

¹⁰ The list of concerns and viewpoints is intended to grow in new releases of the CMRA specification along with blueprints and architecture views on the existing ones.

1.4 Approach

The approach adopted in the design of the CMRA considers the concept of Circular Manufacturing Data Platforms serving as central enablers for a number of tools, services, and utilities which are data-driven and purpose specific solutions to relevant CMRA concerns. The approach draws inspiration from the microservices architecture model pioneered by the ICT domain. Such a model was designed to establish an efficient management framework for an Ecosystem of Services, in which well-defined service models and interfaces accelerate seamless interactions, while maintaining the integrity of individual services. Such an alignment between the microservices architecture model in ICT and circular manufacturing is founded on three fundamental concepts:

- *Products* are considered resources undergoing multiple transformations throughout their lifetime
- *Circular Manufacturing Services* consist in executing the necessary processes to carry out one of the transformations specified in the lifetime of a given circular product type
- *Manufacturers* act as Circular Manufacturing Service Providers for one or more Circular Manufacturing Services in Circular Supply Chains

In practice, the design and implementation of actual CMRA based systems is driven by real-world manufacturing business cases which reveal their needs and bring the ultimate requirements and objectives of target solutions. The CIRCULOOS project brings the ideal enabling context to carry out an iterative end-user driven process for the CMRA design. Three long-term pilots on circular manufacturing business cases hosted by the project along with 16+ external projects addressing circular manufacturing supply chain problems will bring the experience and business based guidance into the CMRA specification and its open reference implementation.

2 The Circular Manufacturing Reference Architecture

In response to the increasing demand for sustainable manufacturing practices, the Circular Manufacturing Reference Architecture initiative aims to bring an open reference model that accelerates the creation of innovative solutions to enhance the sustainability, resilience, and circularity of manufacturing supply chains. Tailored for both MSMEs and large manufacturers, the emphasis is on enabling the design of effective solutions to reduce waste, streamline resource utilization, and champion sustainability across all facets of the supply chain within intricate manufacturing ecosystems.

As a first release of the CMRA specification, the current document focuses on design aspects that aim to accelerate the implementation of functional data platforms for circular manufacturing. The work is being carried out under the umbrella of the [CIRCULOOS](#)¹¹ Innovation Action but, as a reference architecture, the CMRA specification aims to remain agnostic to specific technologies, approaches and reference implementations. Thus, the document is split into two major chapters. The abstract specification of the CMRA is presented in Chapter 2, then the reference implementation undertaken in CIRCULOOS is covered in Chapter 3. Finally, Chapter 4 draws some conclusions on the current CMRA design and next steps.

The CMRA specifications rely on best practices and recommendations from the standard [ISO 42010](#)¹². The topics covered in the current version of the CMRA include:

- [Stakeholders Definition](#)
- [Problem Description and Reference Scenarios](#)
- [Target Capabilities](#)
- [Design Principles](#)
- [Assumptions](#)
- [Prioritized Concerns and Architectural Viewpoints](#)

At this point, the development of a first reference implementation for the CMRA is in very early stages and most of the architecture views giving answers to the prioritized concerns and viewpoints are work in progress. The next release of the CMRA will extend the current topics with such views.

2.1 Stakeholders Definition

The CMRA framework looks at the problem of circular manufacturing from two viewpoints:

- A. It looks at the interaction/collaboration of small businesses, where each small business is a link in the chain of product transformations and
- B. It looks at the influence of a 'big-player' (large manufacturing company) on its suppliers (usually small businesses). This influence is not restricted to just one link of the supply chain upstream, but it is assumed that this 'big-player' has the capacity to affect

¹¹ Innovation Action: 101092295 - CIRCULOOS Circular and Dynamic Manufacturing Supply Chain Orchestration and Optimisation

¹² <http://www.iso-architecture.org/42010/>

sustainability metrics over multiple steps upstream (multiple steps can be thought of in a recursive manner: ‘the supplier of my supplier’).

In the first case the small businesses collaborate in the sense of being members of a ‘circular community’, where actors make their waste/byproducts available for consumption by other actors or offer services in the context of circular economy (‘recycle’ or ‘waste-sorting’ services could be examples). In the second case the large company acts as a central authority with the capacity to build and affect the composition of its supply chain, that is it has the capacity to choose from a pool of potential suppliers those with the minimum cost (‘cost’ is understood here in the sense of an optimization criterion, relevant to some sustainability indexes). Both actors are considered the main types of end-users who are targeted by the Circuloos platform. The scenarios under which they are assumed to act are described below.

Manufacturing SME

A small to medium-sized manufacturing enterprise, specializing in a selected portfolio of products. eager to embrace contemporary methodologies, digitization, and more sustainable production models, but yet lacking the know-how and in-depth expertise to design and carry out the required transformation process.

MSMEs typically engage with a limited circle of trusted collaborators, drawn from past successful partnerships. The aim of the CMRA is to accelerate the creation of value enabling digital assets which allow them to accelerate their transition towards a more collaborative supply chain ecosystem, where MSMEs can connect with trusted partners, access relevant data and insights, and leverage innovative solutions tailored to their unique needs. MSMEs under this viewpoint act as ‘community members’ with the motivation to promote the sustainability practices - as an internal activity.

Large Manufacturer

A leading manufacturing corporation (example could be large automotive manufacturers or a large apparel brand) is committed to maximizing the use of circular products and to ensuring that sustainability metrics are set across the entire product lifecycle (not only at the stages at which the large company handles). Its vision goes beyond the optimization of internal production processes, prioritizing the eco-friendly journey from material acquisition to product delivery. With the ability to plan production activities for the long term, it selectively collaborates with partners, tailoring relationships to specific needs; such needs could arise periodically as in the creation of seasonal apparel collections.

The CMRA aims to help develop data-driven business models and technology solutions which help Large Manufacturers make strategic decisions, optimize supply chain operations, and enhance their product sustainability. For them, CMRA based solutions are accelerators of circular manufacturing supply chains by enabling not only to streamline sustainable production processes and the exchange of waste/byproducts and associated transactions but also the agile creation of new circular supply chain networks to address constantly evolving market demands and enhance resilience against unforeseen disruptions.

2.2 Problem Description and Reference Scenarios

At its core, the CMRA addresses the multifaceted challenges faced by manufacturers in adopting circular manufacturing practices.

From the perspective of MSMEs, the need to navigate the transition towards sustainable production models while lacking in-depth technical (IT) expertise poses a significant hurdle. The CMRA must contribute to solve the problems they face to

- monetizing their production waste and by-products,
- establishing new collaborative partnerships, and
- generating data-driven insights to accelerate their sustainability journey.

In turn, for large manufacturers, the imperative lies in maximizing circularity and sustainability throughout the product life cycle at all stages and this means being able to

- influence manufacturer flows from other tiers/production stages (including MSMEs)
- when necessary, create and/or reorganize existing partnerships in brand new value chains.

Table 1 CMRA Reference Scenarios

Name	Long Title	Full Description
Scenario I: (User Onboarding)	MSME joins a CMRA ecosystem	MSME wants to gain access to a digital space to make profit out of their production waste/by-products & find new companies to work with (in the context of circular economy).
Scenario II: (User Posting)	MSME sells waste and/or by-products through the CMRA ecosystem	MSME wants to make profit out of their production waste/by-products; the first step to do that is to create a visible advertisement that reaches out to a critical mass of potential customers.
Scenario III: (User Transaction)	MSME buys waste and/or by-products as resources	MSMEs have the possibility to explore a catalog with the ads on MSME waste/by-product offerings as well as to buy material for their scheduled production (in the case of material that comes from recycling, upcycling, ...).
Scenario IV: User/Product Catalogs & Inventories	Large Producer establishes new Supply Chain	A Large Manufacturer wants to establish a new product-line. It wants to establish a new supply chain, specifically for this product-line, that minimizes the total footprint (some metric derived from LCA) of production & logistics. The way they approach this problem is by looking at the production processes/capabilities of many companies, from an inventory of potential partners. The ultimate goal is to find the best group of companies that can achieve the desired footprint minimization by making up, activating, and running a brand new supply chain.

2.3 Target Capabilities

Capabilities serve as abstract representations of what is necessary to achieve a desired outcome, incorporating goals and metrics to measure success. The following Table II is meant to highlight the major **groups of capabilities** which are more likely to be interdependent and/or tightly coupled in a CMRA based platform. Building on these categories, the CMRA aims to separate concerns and accelerate reusable capabilities which are agnostic to the way other capabilities are fulfilled.

Table 2 CMRA Capability Categories

Cat. Nº	Capability Category	Category Description
0	Field Equipment / Device Capabilities	Capabilities that enable the physical manufacturing environment to be measured and controlled by information systems.
1	Communications, Interoperability and Data Sharing	Capabilities that enable the exchange of data not only between applications, field equipment, and IT systems running locally and/or private clouds but also with external networks and information systems across the supply chain.
2	Asset and Operations Management	Capabilities that enable the deployment, provision, and activation of the assets and services that aim to support the device communications and IT system integrations.
3	Data Management and Analytics	Capabilities that enable the use of data from ingestion, through local processing and analysis stages to external sharing and publication.
4	Integration & Orchestration	Capabilities to manage and orchestrate the processes and services that aim to support manual and computational activities.
5	Generic Capabilities for Smart Manufacturing and Supply Chain Management	Capabilities that enable the deployment of generic capabilities that may not contribute to one specific circularity concern but help deal with a well-known and relevant concern within the smart manufacturing domain.
6	Domain Specific Capabilities for Circular Manufacturing Operations and Supply Chain Management	Capabilities that enable the deployment of specific accelerators and/or enabling features for circularity manufacturing practices not only for local and internal manufacturing processes but also for global processes that involve multiple supply chain participants and their interactions.
7	Stakeholder Engagement and Collaboration	Capabilities that enable supply chain participants to engage and collaborate with a large variety of stakeholders and collaborate towards strategic goals
8	Security, Sovereignty, and Trust	Capabilities enabling integral security and trust apply across physical sites and assets, devices, systems, and people. Ultimate aim is to protect confidentiality, availability and integrity in a trusted digital context.
9	Common Services	Enabling and/or supportive Capabilities that accelerate other Capabilities regardless of the layer in which the Capability is found.

These capabilities can be translated into actionable steps by aligning them with requisite human resources, processes, technologies, information, and assets. Alternatively, capabilities can be associated with various services that collectively enable their realization, encompassing IT application services, technical services, external services, and more.

Capability Map

Organizing capabilities into structured maps (Figure 2) facilitates planning and evaluation, revealing existing strengths, areas for improvement, and gaps in functionality. Capabilities are instrumental in understanding the implications of industry drivers, establishing priorities, and directing investments effectively.

Specific Capabilities Per Category

For each category a set of more granular capabilities can be identified to determine the scope of solutions which help address specific problems or concerns. Some examples of specific capabilities for each of the categories are given in the image below.

Capability Matrices and Cross-Cutting Concerns

Categories and Specific Capabilities can be interconnected through many-to-many relationships with organizational processes, services, personnel, departments, and IT applications (or their modules). This linkage is often visualized through an Application/Capability Matrix (or a series of them). This is often the case for almost every capability in categories 1, 8, and 9 (Communications and interoperability, Security and Trust, and common services).



Figure 2 The CMRA Capability Map

2.4 Design Principles

The design principles for the CMRA system emphasize creating robust, adaptable, and secure manufacturing solutions that cater to diverse industrial needs. These principles are essential for ensuring that manufacturing systems are efficient, sustainable, and capable of evolving with technological advancements and market demands.

Reusability focuses on designing components that can be applied across various sectors, accommodating different manufacturer sizes and product life cycles. This principle advocates for the seamless integration of materials and products into circular supply chains, promoting sustainability through the most convenient R-strategy (e.g., recovery, recycling, or repurposing supply chain flows). Additionally, by implementing standardized interfaces, CMRA based platform components aim to be easily integrable into both legacy and homegrown manufacturing systems.

Modularity involves breaking down manufacturing processes into smaller, specialized problems which can be solved by purpose specific software modules. This modular approach simplifies maintenance and upgrades, making it easier to address specific problems without disrupting the entire system. Standardized communication between modules, facilitated by open standards-based APIs and data models, is essential to ensure interoperability and enhance the flexibility required in modular solutions. Ultimate goal is that modules are designed with replaceability and upgradeability in mind so they can be easily swapped or enhanced to further support system adaptability while remaining cost-effective.

Portability aims to ensure that CMRA based solutions for circular manufacturing systems are compatible with various environments and locations, facilitating easy adaptation and replicability between facilities. To that aim, promoting edge- and cloud-native solutions allows for more straightforward deployment and maintenance, making CMRA-based platforms more versatile and accessible across different operational contexts.

Scalability is also crucial for accommodating the digital manufacturing systems to varying production demands. Systems must be designed to handle fluctuations in workload, with flexible resource allocation to manage increases or decreases efficiently. The ability to scale manufacturing processes up or down without significant reconfiguration or disruption shall be pursued to ensure that CMRA based platforms continuously meet evolving business needs effectively.

Last but not least, **Security and Trust** principles are critical to prioritize protecting sensitive manufacturing data through robust access controls and secure communication features. For instance, cybersecurity measures are essential to prevent unauthorized access or tampering with manufacturing processes.

Regarding trust aspects, accelerating interfaces with reference trust services, such as the Verifiable Credentials Framework¹³, is key to ensure that CMRA based solutions bring a high level of trust and

¹³ <https://ec.europa.eu/digital-building-blocks/sites/display/EBSI/EBSI+Verifiable+Credentials>

integrity in its operations, safeguarding against potential threats and maintaining the reliability of manufacturing processes.

2.5 Assumptions

The CMRA considers the use of CMRA based data platforms as a core enabler of circular manufacturing value chains. However, the convenient design and implementation of such data platforms is still full of challenges, problems, and open questions. The following assumptions aim to provide a foundation for making it feasible to cope with such complexities and achieve meaningful platform Minimum Viable Products (MVPs), and Proof-of Concepts (PoCs).

Table 3 Assumptions made for feasible CMRA based data platform designs

Assumptions	Description
Environmental Awareness and Regulatory Compliance	<ul style="list-style-type: none"> ● CMRA based data platforms will incorporate sustainability assessment tools and compliance monitoring features to measure the environmental performances of manufacturing processes, ensuring adherence to regulations and standards. ● Existing sustainability assessment frameworks will be leveraged to ease the evaluation of environmental and social impacts and streamline CMRA based innovation.
Availability of Enabling Technologies and Infrastructure	<ul style="list-style-type: none"> ● CMRA based platforms build on the availability of foundational technologies such as IoT devices, big data analytics, machine learning, and cloud computing, ensuring the feasibility of collecting, analyzing, and managing supply chain data at scale. ● The existence of robust infrastructure, including high-speed internet connectivity, ample data storage, and processing capabilities, is assumed to support the implementation and operation of the data platform through incremental improvements, avoiding major infrastructure overhauls.
Access to Resources	<ul style="list-style-type: none"> ● CMRA based platforms assume the accessibility to essential resources, including raw materials, components, energy, and skilled labor, to enable the targeted circular manufacturing processes. It is also assumed that management features are already in place for those essential resources, being the platform is responsible for enabling their seamless integration with advanced circularity services. ● Existing circular design principles and resource recovery strategies are assumed to be in place, providing a foundation for connecting by-products and waste streams with sustainable initiatives (e.g., R-strategy flows) within the platform. ● Collaboration features will enable and stimulate the offering and purchase of circular products. Additionally, collaboration features will support the manufacturers with effective means to join existing and/or engage in brand new supply chains. It is also assumed that collaboration features exist to help manufacturers share resources, knowledge, and expertise across the supply chain.
Economic Viability	<ul style="list-style-type: none"> ● It is assumed that CMRA based platform's designs build on top of cost optimization frameworks and resource efficient models as well as a consistent business plan so that derived platforms enable not only platform and service provider but also manufacturer businesses to achieve economic viability within the targeted circular manufacturing chain ecosystems. ● Stakeholder engagement mechanisms, including collaboration tools and marketplace features, are assumed to exist with a clear target on facilitating the connection and the exchange of resources, ideas, and best practices among participants, contributing to both the development of greater and more sustainable manufacturer businesses and to

the economic sustainability of the CMRA based platform.

2.6 Prioritized Concerns and Architectural Viewpoints

In complex systems and platform architecture design, concerns and viewpoints play a crucial role in structuring and understanding of the problems to be solved as well as of the value proposition of alternative approaches to provide effective solutions. While concerns emphasize on representing areas of interest or focus on design problems within a system, the viewpoints aim to provide perspectives or lenses through which these concerns are examined and addressed. The ultimate goal of viewpoints is to help stakeholders analyze and communicate different aspects of a system's architecture, facilitating effective decision-making and problem-solving that results in a satisfactory architecture view which can be later on implemented by an actual system.

Prioritization Criteria in the selection of Concerns and Viewpoints

The scope for prioritizing concerns and viewpoints in the context of a reference architecture for enabling and accelerating circular manufacturing supply chains spans a vast landscape. In order to make the first iteration on the design of the CMRA a feasible exercise, the prioritized concerns and viewpoints are those which aim to help achieve major objectives of the [CIRCULOOS](#)¹⁴ Innovation Action. Therefore, the following list is not meant to be an exhaustive list of concerns and viewpoints for the CMRA but just an initial one:

- Core Enabling Features for Federated Circular Supply Chains
- Supply Chain Optimisation Capabilities
- Supply Chain Process Orchestration and Execution Capabilities
- Stakeholder Engagement Capabilities
- Reusable tools for MSMEs vertical solution development

The list of concerns and viewpoints presented above is intended to grow in new releases of the CMRA specification along with blueprints and architecture views on the existing ones.

2.6.1 Concerns and Viewpoints on Enabling Features for Federated Supply Chains

On the one hand, the digitization of manufacturing facilities plays a fundamental role in enabling value-added services within circular supply chains. Data layers implemented by manufacturers in concrete vertical solutions serve as sources of crucial information, capturing granular details about processes, materials, and interactions at the manufacturing facility level. Thus, specific architectural views should focus on the design of solutions to facilitate seamless access and utilization of manufacturing digitization tools across diverse manufacturing facilities and stakeholder types.

On the other hand, as supply chains become increasingly interconnected and interdependent, the ability to share data securely and confidently becomes paramount. Secure and Trustworthy Data Sharing is fundamental to the development of value-added services that leverage shared data insights to drive innovation and optimization within circular supply chains. Thus, architectural

¹⁴ Innovation Action: 101092295 - CIRCULOOS Circular and Dynamic Manufacturing Supply Chain Orchestration and Optimisation

views addressing robust data encryption, access controls, and identity management mechanisms are also of high priority.

2.6.2 Concerns and Viewpoints on Supply Chain Optimisation Capabilities

In this category, concerns and viewpoints which emphasize the local needs of manufacturers in their own facilities mostly focus on problems related to model-based and data-driven approaches to analyze running processes, resource availability, and production capacity estimations. Outside the boundaries of the manufacturing facility, the challenges are associated with concerns and viewpoints which look for effective views and solutions to determine supply chain arrangements and yield optimal supply chain processes by connecting production capacity and demand forecasting features with the actual offerings and orderings registered by the circular supply chain.

2.6.3 Supply Chain Process Orchestration and Execution Capabilities

The relevant concerns and viewpoints on process orchestration and execution capabilities for the CMRA are quite diverse. They mainly revolve around the need for an integrated tool that helps solve a wide range of heterogeneous problems. This means that architecture views and solutions for orchestration and execution shall cover features for aggregating local data from production processes, modeling and creating global digital replicas of the real-world processes, composing aggregate processes across the supply chain, monitoring the global process execution and, finally, assigns tasks or at least recommending convenient actions to the local processes being carried out by the IT systems, cyber-physical assets, and personnel of the supply chain participants involved.

2.6.4 Stakeholder Engagement Capabilities

In the CMRA, the concerns and viewpoints on stakeholder engagement aspects are mostly focused on the challenges and problems associated with digital marketplace approaches. Architecture views and solutions are expected to address the design and implementation of digital marketplaces as digital environments which enable holistic, effective, and attractive user experience for an integrated series of features such as community building tools, organizations and inventory catalogs, matchmaking services, training, and dedicated support implementation of circular practices. In practice, this implies addressing the challenging design of successful functionalities for:

- enabling user onboarding (registration, profile display pages) and user interaction (messaging, request to develop a new service)
- creating and managing registries and/or communities of MSMEs with the potential to work together in a circular context
- promoting those interactions that are more likely to happen (for example connect companies that are geographically closer)
- automating and offering convenient frontend tools (marketplaces) to handle relevant steps in the search process for new resources, analyzing the data available in the digital platform.

2.6.5 Reusable tools for MSMEs vertical solution development

In the manufacturing sector, digitisation is still a great challenge and the potentiality for concerns and viewpoints in this dimension is endless. In the context of CMRA, prioritized architecture views in this category include: i) I4.0 Connectors for Trustworthy Data Sharing, ii) Advanced Circularity

Model Builders; iii) Low/No Code Model Composers, iv) Reconfigurable User Centric Apps, v) software for demand and production capacity forecasting and vi) IoT enabled perception and cyber-physical automation tools.

3 A Reference Implementation: The CIRCULOOS Data Platform

3.1 Overall Context

3.1.1 The CIRCULOOS Project

The CIRCULOOS platform builds on the CMRA model and aims to accelerate circular manufacturing chains by seamlessly integrating orchestration, sustainability assessment, and optimization features. Its primary aim is to equip manufacturers with the necessary tools to embrace and champion sustainable production practices throughout the entire lifecycle of products. This encompasses everything from resource acquisition to the creation of subassemblies, kits, and final products, culminating in their reincorporation as resources (not necessarily in the same supply chain). However, demonstrating and validating the CIRCULOOS approach as enabler of novel circular business processes is not straightforward. The CIRCULOOS project needs to put in place the right platform capabilities to generate evidence of effective support to manufacturers that results in measurable impact such as:

1. Increased and/or improved connections between direct supply chain flows generating waste, by-products, and End-of-Life (EoL) products reverse R-strategy flows which allow their reinjection as resources in a new supply chain (see the diagram in Figure 3).
2. Increased number of loops demonstrating successful circularity and/or greater efficiency in closing, extending and narrowing existing ones.

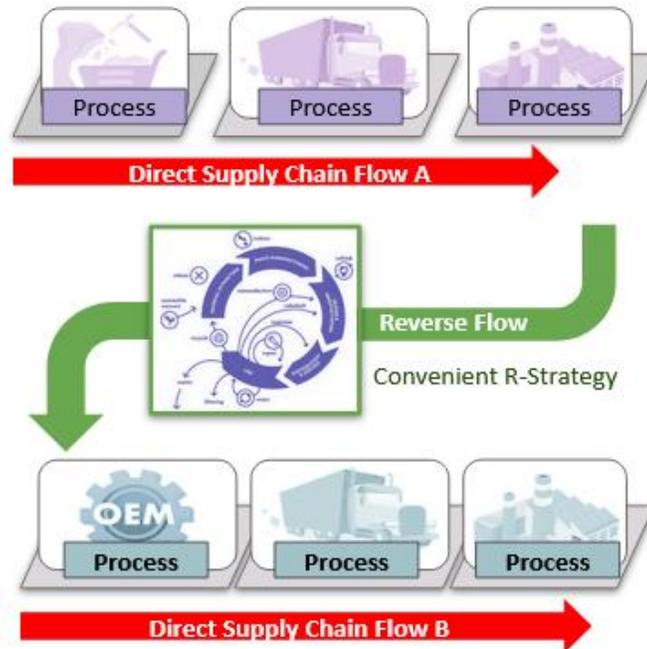


Figure 3 Direct Supply Chain represent linear supply chain models while the reverse flows are circularity enablers implemented by R-strategies

3.1.2 Target Capabilities and Prioritized Platform Objectives

The CIRCULOOS platform emerges as an open reference implementation of a series of [CMRA target capabilities \(Section 2.3\)](#) in a fully integrated software ecosystem that addresses the [Prioritized Concerns and Architectural Viewpoints \(Section 2.6\)](#). To that aim, the current list of prioritized CIRCULOOS platform objectives includes:

1. Reusable tools for MSMEs vertical solution development: providing a comprehensive suite of customizable software modules and frameworks tailored specifically for the needs and challenges faced by MSMEs. Since data is the essential resource for the CIRCULOOS platform to become operative, the major aim of these tools is to accelerate the digital transformation of MSMEs by bringing efficiency and cost-effectiveness into the design, implementation, deployment, and maintenance of vertical data-driven solutions.
2. Circular End-to-End Supply Chain Orchestration: Implementing collaborative workflows integrating planning and execution metrics, alongside advanced visualizations and analytics. Visualizations are facilitated through comprehensive Digital Twins representing supply chains, factory processes, and product design phases.
3. Supply Chain Optimization: Monitoring both global (across the supply chain) and local (within the factory) processes and executions, analyzing inputs, outputs, and configuration parameters. This enables data-driven AI decision-making, supporting continuous optimization of performance and sustainability parameters.

4. **Dynamic Sustainability Assessment:** Assessing alternative supply chain scenarios quickly, including variations in materials, processing technologies, suppliers, and circular economy practices. This assessment measures sustainability and circular economy profiles.
5. **Supply Chain Data Spaces:** Facilitating seamless, multi-level data flow across supply chain partners. This supports material reuse, product lifecycle extension (e.g., remanufacturing), and data-driven collaboration decisions efficiently.
6. **Cybersecure Data Sharing:** Ensuring secure data sharing across the supply chain using a distributed, trusted Identity and Access Management system. This system coordinates IoT object identities and enables trustworthy data sharing among members, aligning with established trust frameworks.
7. **Customized Tools for Circular Manufacturing:** Developing tools for automatic recognition of recyclable parts using modern Machine Vision and Advanced Robotics. This optimizes selection processes for recyclable materials.

It is crucial to emphasize that the development of the CIRCULOOS Platform aims to be use case driven and result in a catalytic system for realizing the target CMRA capabilities in real-world settings. Consequently, to ensure alignment between the platform's requirement specifications, integrations, and tests with actual manufacturer needs, three industrial pilots hosted by the CIRCULOOS project engage in daily collaboration with platform developers to steer its design and objectives for the first release. In future releases, the platform resulting from this work will be tested and extended not only by the hosted pilots but also by 16+ external projects that will receive funding from the CIRCULOOS innovation action.

3.1.3 Overview of CIRCULOOS Industrial Pilot Requirements

The project internal pilots have been analysed in more detail in the respective project report D2.1. They are briefly outlined here for ease of reference.

Pilot 1 – Plastic Industry

In the various industries where recycling is prevalent, plastic manufacturing is among the most well-known and extensively studied¹⁵. Plastic recycling may have significant environmental, economic, and social impacts, making it crucial to increase the proportion of recyclable materials and incorporate them into new products. Consequently, an entity within the plastic industry was chosen as a pilot for the CIRCULOOS project. This plastic pilot involves two companies: Thermolympic and Contenedores LOLO. Thermolympic specializes in producing plastic products, while Contenedores LOLO focuses on producing new plastic materials from plastic waste. The pilot considers multiple scenarios for sustainability assessment, including a current reference scenario mainly relying on virgin material and at least one prospective scenario with a circular alternative for an existing product.

In the current scenario, Thermolympic and Contenedores LOLO operate as independent entities. Improvements planned within CIRCULOOS are meant to maximize the recycling of plastic waste (mainly from production scrap). Contenedores LOLO aims to expand into other industries as part of the CIRCULOOS project. This expansion would increase their revenue while promoting sustainable practices within communities.

In the prospective scenario, the two companies can integrate their activities. Contenedores LOLO plans to handle the recycling of plastic waste from Thermolympic, which would then use the recycled plastic in their production processes. This integration is expected to improve the circular profile of both companies. Using the CIRCULOOS platform, the companies will employ sustainability metrics to guide their (even batch-wise) decision-making in selecting the circular approach(es), maximizing the combination of economic and environmental sustainability.

Pilot 2 – Leather Industry

The leather industry represents another sector where recycling initiatives can significantly enhance sustainability performance¹⁶. Although not as widely recognized as plastic recycling, the leather industry faces its own unique set of challenges and opportunities. Recycling leather can help reduce waste and lower the industry's environmental footprint.

In the CIRCULOOS project, two specific entities within the leather industry, KHOANI and B&A, are examined in the leather pilot to explore the potential benefits and challenges of incorporating recycling practices into leather production. KHOANI and B&A are two distinct companies producing leather goods. KHOANI primarily produces bags, while B&A focuses on smaller leather items such as keyrings. In the prospective scenario, KHOANI and B&A will integrate their activities in a way that allows KHOANI's leftovers, mainly small pieces of leather, to be used for B&A's small products.

¹⁵ <https://doi.org/10.3390/recycling2040024>

¹⁶ Yorgancioglu, A., Başaran, B., & Sancakli, A. (2020). Value Addition to Leather Industry Wastes and By-Products: Hydrolyzed Collagen and Collagen Peptides. IntechOpen. doi: 10.5772/intechopen.92699

This collaboration not only optimizes resource use but also enhances the sustainability of their operations.

Additionally, improving circularity and sustainability practices for both KHOANI and B&A could involve selling leftover materials on an online marketplace exposed by the CMR. This approach would reduce environmental impacts, such as lowering the carbon footprint by using leftovers instead of virgin leather. The associated environmental benefits could be reflected in the pricing catalog, potentially increasing the incomes of both companies while enhancing the sustainability of the communities they serve. This innovative approach underscores the economic and ecological advantages of integrating recycling practices in the leather industry.

Pilot 3 – Wood Industry

Recycling also plays a crucial role in the wood industry, where the wasted or end-of-life material is often viewed primarily as a source of energy. However, new trends emphasize the need to extend the lifespan of wood, challenging this conventional perception. Previous analyses of waste wood management, whether through recycling or conversion into bioenergy, have tended to overlook the alternative use of freshly preserved wood resulting from recycling processes. This aspect requires careful consideration within European energy policy and market dynamics. Imagining a scenario where preserved wood is used as an energy resource challenges the notion that waste wood recycling inherently provides substantial environmental benefits. This calls for a re-evaluation of the waste hierarchy principle, questioning the prioritization of material reuse over energy production.

In the CIRCULOOS project, a wood pilot was selected to focus on enhancing the longevity of wood materials. This pilot involves two companies: Fiction Factory and HERSO. Fiction Factory produces wood furniture, while HERSO produces recycled wood material from both pre-consumption (forestry waste) and post-consumption (old furniture or city waste). This recycled wood is mainly sold as building materials, which are subject to stringent regulations in many countries. As a result, HERSO needs to certify their wood to meet these environmental legislations.

On the other hand, Fiction Factory is committed to sustainability, with a brand philosophy deeply rooted in sustainable practices. In the prospective scenario within the CIRCULOOS project, Fiction Factory and HERSO would integrate their activities by using HERSO's certified recycled wood building materials in Fiction Factory's processes to produce circular and sustainable furniture.

HERSO's primary goal is to obtain certification for their recycled building materials to demonstrate compliance with specific regulations to their clients in the building sector. Fiction Factory aims to measure and enhance circularity and sustainability in their business, as they need to demonstrate continuous improvement aligned with their philosophy of a circular and sustainable business model. This integrated approach not only addresses regulatory compliance and sustainability goals but also exemplifies how extending the lifespan of wood products can lead to innovative and beneficial practices within the wood industry.

3.2 CIRCULOOS Platform Description (Design Phase)

The design of the CIRCULOOS platform remains in a conceptual stage since a number of circularity tools and enablers are still under development. An updated version of the CMRA will be published in 2025 (Q1/Q2) and that version will include the description of a functional CIRCULOOS platform. The main building blocks of the current design that will be implemented and integrated in the functional platform are classified as follows:

- [Generic Platform Capabilities and Software Enablers](#)
 - [Local Data Platform](#)
 - [Data Sharing Framework](#)
- [Circular Manufacturing Capabilities and Software Enablers](#)
 - [Stakeholder Engagement and Collaboration \(RAMP\)](#)
 - [Manufacturing Process Orchestration \(MPMS Tool\)](#)
 - [Sustainability Assessment \(GRETA Tool\)](#)
 - [Supply Chain Digital Twin \(SCDT Tool\)](#)
 - [Supply Chain Optimization \(SCOPT Tool\)](#)
 - [CV-based system for composition detection](#)

The following subsections contribute a brief description of each building block along with the role and capabilities that they will bring into the functional platform. Detailed architecture views emphasizing the CMRA concerns, viewpoints and capabilities implemented by each building block for the functional platform will be delivered in the next release of the CMRA specification.

3.2.1 Generic Platform Capabilities and Software Enablers

The design and implementation of generic platform capabilities for the CIRCULOOS platform mostly aim to contribute to the prioritized concern *Core Enabling Features for Federated Circular Supply Chains*. The purpose for these capabilities is two-fold:

- On the one hand, the generic platform capabilities are enablers and accelerators of digitization for the manufacturing facilities. This means that generic platform capabilities aim to contribute to the efficient and cost-effective implementation of vertical solutions for smart manufacturing as *Local Data Layers*. Major objectives of the local data layers include not only enabling local process/resource monitoring and optimization but also putting in place the necessary interfaces to the data sharing framework of the global supply chain.
- On the other hand, since circular supply chains require manufacturers to become increasingly interconnected and interdependent with external organizations, the ability to share data in a secure and trustworthy environment becomes paramount. Thus, along with Local Data Layer enablers, the enabling capabilities for a secure and trustworthy *Data Sharing Framework* are central to the generic platform capabilities and software enablers.

The current design of the CIRCULOOS platform already considers i) a top level architecture view for the integration of Local Data Layers and circularity services through a Trustworthy Data Sharing Framework and ii) a more granular architecture view for the implementation of Local data Layers.

Figure 4 shows a *Top Level View of the major building blocks in the CIRCULOOS Platform*. In it, manufacturer facilities and cyber-physical real-world activities¹⁷ are shown in what the CIRCULOOS model refers to as *Observable Layers*. On top of the observable layers, *Local Data Layers* (Figure 5) implement, for each supply chain participant, the vertical solution and interfacing capabilities required to interact with the Global Data Layer through the *Data Sharing Framework*. At the local level, there is a clear distinction between the i) *digital background*, sensitive data flows and repositories which are sensitive to the manufacturer and opaque to the CIRCULOOS data platform and the ii) *digital foreground*, data flows and repositories that the manufacturer exposes through convenient interfaces to the CIRCULOOS platform to interact with added value circularity services. Examples of added value services include sustainability assessment, manufacturing process orchestration, supply chain modeling and optimization, marketplaces, etc.¹⁸ Regarding the reference model for the delivery of added value circularity services to the digital foreground of manufacturers, the key consideration is that technical approaches and deployment types are extremely dependent on the objectives, scope and particular end user requirements for each service. Therefore, they may vary from embedded local service instances run by local or far edge systems through hybrid cloud native approaches relying on edge/cloud deployments, to cloud-based global services delivering value to the local data layers through the trustworthy data sharing framework. In order to offer an open reference implementation of a system environment that fulfills the requirements of the aforementioned context, the CIRCULOOS project is working on two major generic enablers for the CIRCULOOS platform: the [CIRCULOOS Local Data Platform](#) and the [CIRCULOOS Data Sharing Framework](#). Both enablers are better described next in dedicated subsections (Sections 3.2.1.1 and 3.2.1.2).

To offer a complete solution the inclusion of a cybersecure, trustworthy data-sharing framework that integrates robust Identity and Access Management (IAM) with Verifiable Credentials (VC) and Verifiable Presentations (VP) has been considered. The system can incorporate decentralized identifiers (DIDs) for unique user identification and employs role-based access control (RBAC) to manage permissions and access. Trusted entities can issue VCs to users and IoT agents, which serve as cryptographic proof of identity and attributes. IoT agents, acting as autonomous devices, can hold and present these VCs as VPs, which are verified for authenticity and integrity by the receiving parties. Data security is reinforced through strong encryption, data minimization, and anonymization techniques, ensuring data is shared securely and only when necessary. This framework follows the current technical trend for the protection of sensitive information, ensuring that only authorized and verified entities, including IoT devices, can access critical data.

Emphasizing access control, the use of RBAC ensures that each user or device has access only to the data necessary for their role, thereby reducing the risk of unauthorized access and potential data breaches. The system's design addresses the growing need for secure data exchange in an increasingly interconnected world, providing a reliable means of verifying identities and maintaining data integrity. The benefits include improved data protection, streamlined identity verification, reduced risk of data breaches, and enhanced user trust and confidence in the data-

¹⁷ Physical actions in manufacturing sectors implemented by humans, machines or a combination of both

¹⁸ For the first release of the CIRCULOOS platform the prioritized added value services are those contributing capabilities to the concerns and viewpoints described in [Section 2.6](#)

sharing process, along with the ability to securely integrate and manage IoT devices in the data ecosystem.

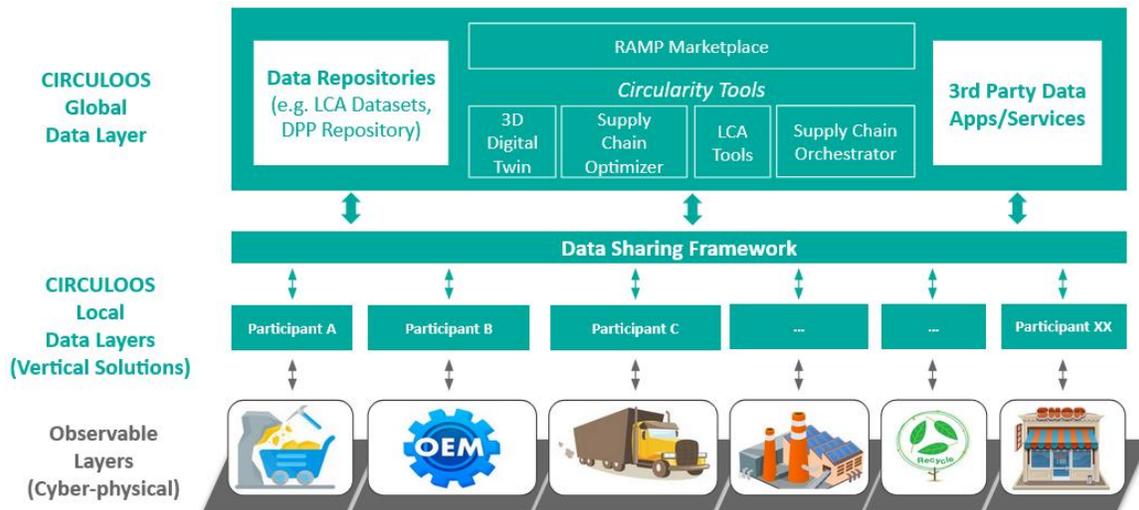


Figure 4 Top Level View of the CIRCULOOS Platform (Global + Local Data Layers)

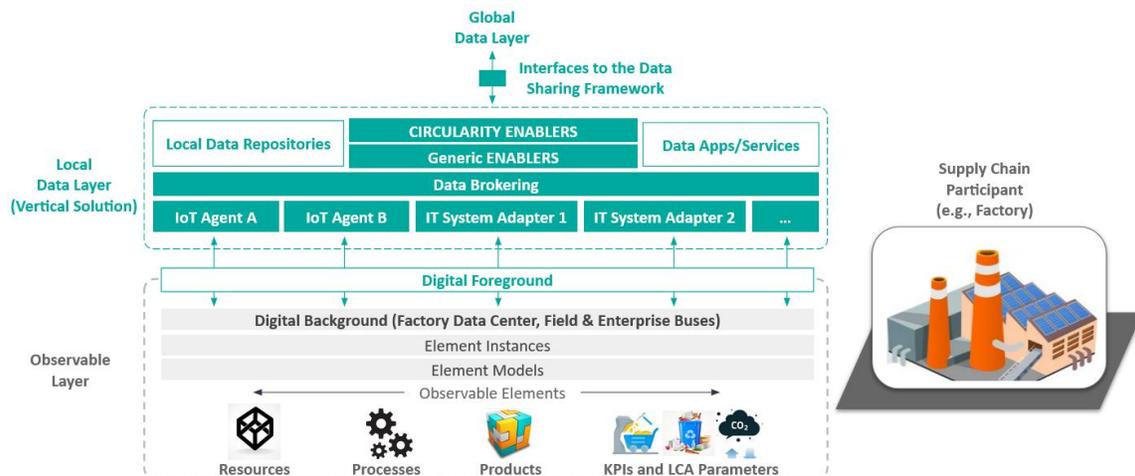


Figure 5 Detailed View of a Local Data Layer (Vertical Solution of a single Supply Chain Participant)

Along with the presented architecture views, the generic software capabilities of the CIRCULOOS platform already account for a preliminary integration which will release an official CIRCULOOS platform MVP.

3.2.1.1 Local Data Platform

To enable simple installation of both testing and production environments, the Local Data Platform is built using Docker containers. This platform utilizes standard FIWARE components, ensuring compatibility and ease of integration with existing systems. The Local Data Platform is designed to serve as a template, equipped with minimal configurations to facilitate a smooth startup process. It already implements and integrates some of the core building blocks of the CIRCULOOS Platform

view and is designed to be used on-premise. The aim is to ensure the smooth transition for end-users between the Local Data Platform and a hybrid cloud/edge or 100% cloud-based CIRCULOOS platform without the need for extensive reconfiguration or adaptation.

One of the primary purposes of the Local Data Platform is to familiarize users with the Generic CIRCULOOS platform through hands-on experience. By providing a local, easily deployable version, users can experiment and learn the system's functionalities in a controlled environment. This approach helps in building user confidence and understanding, making the transition to the Generic platform more seamless and efficient. In this regard, the use of Docker containers in the Local Data Platform is key to ensure that installation and setup processes are straightforward. The containers encapsulate all necessary software dependencies and configurations, allowing for a consistent and reproducible environment. This makes it easier for users to deploy the platform in both testing and production scenarios, reducing the complexity and potential for configuration errors.

In summary, the Local Data Platform, built with Docker containers and standard FIWARE components, serves as a minimal configuration template to facilitate easy startup and user familiarization with the CIRCULOOS platform with little focus on deployment aspects. Furthermore, its on-premise deployment capability and consistent cloud-native implementation of platform building blocks ensure a smooth and efficient transition for users. (See the platform documentation in [Github](#)¹⁹).

Critically, the Local Data Platform is the foundational element for the Data Sharing Framework, offering a robust base for a distributed and interconnected system. By establishing a federated scheme, the platform ensures scalability, resilience, and a collaborative framework where various entities can interact within a unified ecosystem. The federated scheme is also motivated by user requirements for data sovereignty (ability to selectively expose data they own). This strategic emphasis on federation not only enhances the platform's versatility but also supports a wide range of use cases, from localized deployments to extensive, networked data environments.

3.2.1.2 Data Sharing Framework

The CIRCULOOS Data Sharing Framework is designed to facilitate interoperability and data exchange across diverse systems and domains using a federated scheme. This framework ensures that different systems can communicate and share context information seamlessly, promoting a unified approach to data management for industrial IoT deployments and distributed IT systems, both within manufacturing facilities and for connected remote facilities through hybrid cloud environments.

A core component of this framework is the context broker, which manages context information such as entities, attributes, and relationships. It provides interfaces for querying, updating, and subscribing to changes in context data. Next Generation Service Interfaces - Linked Data (NGSI-LD),

¹⁹ <https://github.com/european-dynamics-rnd/circuloos-data-platform>

a standard API for managing context information, supports linked data principles and enables semantic interoperability, defining how context data should be structured and exchanged.

Federation in this context refers to the process of interconnecting multiple context brokers to enable data sharing and collaboration across different organizations and domains. In a federation architecture, federated context brokers operate independently but are interconnected through federation protocols. Each broker can publish and subscribe to context information from other brokers within the federation. Common data models and schemas are essential for interoperability, and NGS-LD offers a standardized approach to defining entities, attributes, and relationships using linked data principles.

Security and privacy are critical components of federated systems, necessitating authentication, authorization, and encryption mechanisms to ensure secure data exchange and protect sensitive information. Additionally, clear governance structures and policies are necessary to manage data-sharing agreements, access controls, and compliance with regulations.

The federated approach enhances collaboration by allowing multiple organizations to share data without compromising control over their own information. This fosters partnerships and drives innovation across various domains and industries. Scalability is another significant advantage, as federated systems can efficiently distribute the workload across multiple context brokers, reducing bottlenecks and improving overall performance.

Organizations benefit from retaining control over their data, ensuring compliance with local regulations and policies, which is particularly important in industries with strict data governance and privacy requirements. Resource optimization is achieved by processing and managing data closer to its source, reducing latency and improving the efficiency of data-driven operations. Cost efficiency is another key benefit, as sharing infrastructure and resources across multiple organizations can reduce overall costs and provide economies of scale without the need for heavy investment in standalone systems.

The implementation components of this framework include context information management, which involves managing entities, attributes, and relationships in a standardized manner, including CRUD operations (Create, Read, Update, Delete) and advanced query capabilities. Subscription and notification mechanisms support real-time data exchange through subscription to context changes and notifications when changes occur. Cross-broker queries enable queries that span multiple context brokers, allowing for a holistic view of the distributed data landscape. Interoperability middleware facilitates communication and data exchange between different context brokers, handling protocol translations and data format conversions as needed.

In the context information management system, an event *csourceRegistrations* (Figure 6) is triggered by the global CIRCULOOS context broker environment to the local/pilot instance of context broker (Local Orion-LD) for data provided by Context Producer 1. This setup allows any Context Consumer to register and receive updates from Local Consumer 1.

The process works as follows. Context Producer 1 sends data to the local/pilot context broker. Upon receiving the data, the local/pilot context broker can forward relevant information to the CIRCULOOS context broker using the *csourceRegistrations* event. The CIRCULOOS context broker

acts as a higher-level broker that receives forwarded data from the local/pilot context broker. Any Context Consumer registered with the CIRCULOOS context broker can receive updates about this data. Local Consumer 1 is a consumer registered with the local/pilot context broker to receive updates from Context Producer 1.

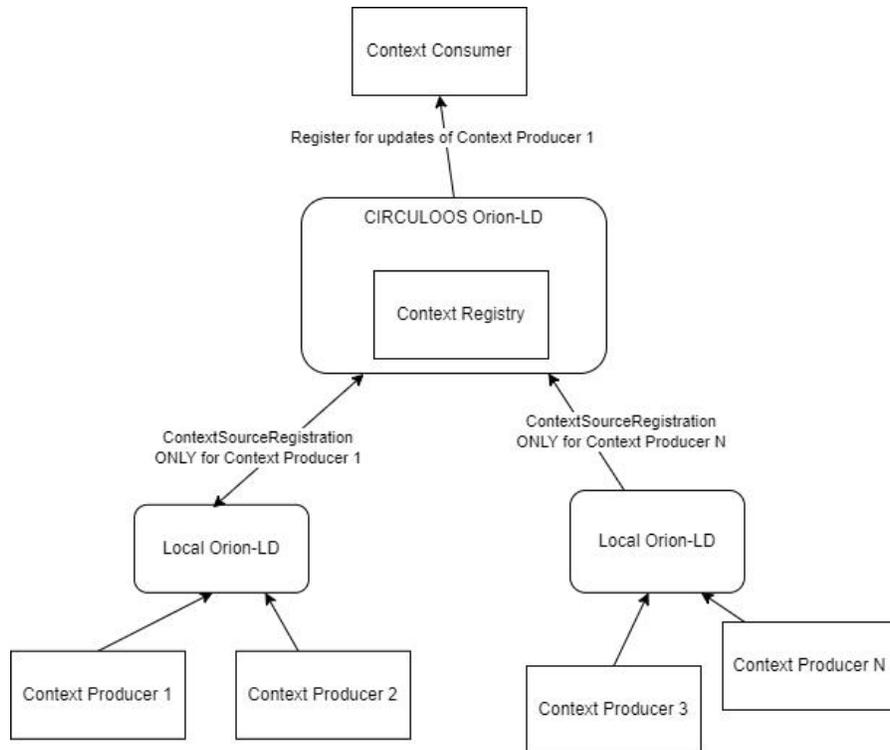


Figure 6 Context Source Registration

Additionally, Data Producer 2 is another data producer that sends data only to the local/pilot context broker. This data is not forwarded to the CIRCULOOS context broker and remains accessible only to consumers registered locally. By utilizing the registration infrastructure of the context broker, a more fine-grained data forwarding scheme can be implemented. For instance, a specific subset of measurements from Context Producer 1 can be selectively forwarded to the CIRCULOOS context broker, allowing for precise control over which data is shared and which remains local.

This example demonstrates how the CIRCULOOS Data sharing Framework can be used to manage context information efficiently, ensuring that data is shared appropriately across different levels of context brokers while maintaining the flexibility to keep certain data local.

Another crucial aspect of the CIRCULOOS platform is to be a cybersecure, trustworthy data-sharing framework that integrates robust Identity and Access Management (IAM) and long-term storage of information.

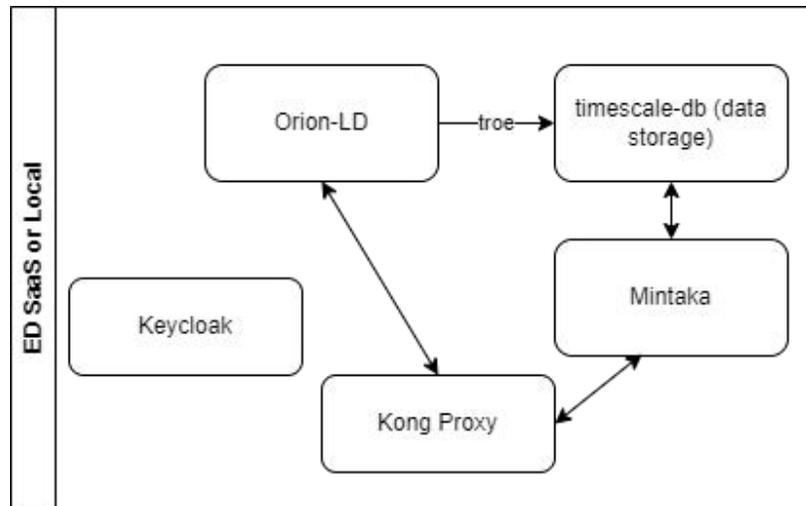


Figure 7 CIRCULOOS Platform main components

The CIRCULOOS Platform utilizes FIWARE components (Figure 7), designed to be implemented on factory premises or in the cloud. It is compatible with the NGSI-LD specifications.

The main components of the CIRCULOOS platform are:

- **Orion-LD as Context Broker:** This component handles real-time data and context information management, ensuring that the platform can ingest, query, and manage data efficiently.
- **Mintaka as NGSI-LD Temporal Retrieval API:** Mintaka facilitates the retrieval of historical data, enabling users to access and analyze past data trends and patterns.
- **Keycloak as a Single Sign-On with Identity and Access Management:** Keycloak manages authentication and authorization processes, ensuring that only authorized users can access specific data and functionalities.
- **Kong as PEP (Policy Enforcement Point) Proxy for Orion-LD and Mintaka:** Kong enforces security policies, acting as a gatekeeper to control access to both real-time and historical data managed by Orion-LD and Mintaka.

To ensure secure and controlled data access, any actor needing to access current data (via Orion-LD), historical data (via Mintaka), or add data to the CIRCULOOS platform must have credentials. These credentials are issued by the platform administrator team, following a strict verification process.

When a new dataset is to be added to the CIRCULOOS platform, the actor (user or device) requesting to add data must first obtain the necessary credentials from the platform administrator. This involves verifying the actor's identity and determining the appropriate access level.

Once credentials are obtained, the actor can submit data through a secure API endpoint. The data must comply with NGS-LD specifications to ensure compatibility and seamless integration into the platform. Upon submission, the data undergoes validation checks to ensure it meets the platform's quality and format standards. This step is crucial for maintaining data integrity and reliability.

Validated data is then stored within the platform. Orion-LD manages the context data, allowing real-time access and updates, while Mintaka handles the temporal data, making historical data available for retrieval and analysis. Throughout the process, access control policies managed by Keycloak and enforced by Kong ensure that only authorized users can interact with the data, maintaining a high level of security and privacy.

By following these procedures, the CIRCULOOS platform ensures that data addition is secure, reliable, and compliant with industry standards, supporting its mission to be a cybersecure, trustworthy data-sharing framework.

3.2.1.3 Blockchain-based services for trustworthy and secure data sharing

The CMRA considers the Blockchain technology as a core enabling element which offers a secure, transparent, and immutable way to manage data and transactions. The pilots and use cases analyzed in the CIRCULOOS project reveal that incorporating Blockchain can enhance various aspects of circular manufacturing by providing robust traceability, facilitating trust among stakeholders, and enabling new economic models. The technical approach for Blockchain integration along with the data platform, and other technical components, will be to provide a REST API for any Blockchain functionality to be used inside CIRCULOOS. Blockchain services will not be the front application for end users, in any case, but designed to be used and integrated with backend applications.

The current selection of features considered as potential blockchain-based services for the next release of the CIRCULOOS data platform include:

- *Traceability and Transparency:* Blockchain can create an immutable ledger of all transactions and processes within the supply chain. Each step, from raw material acquisition to recycling, can be recorded on the Blockchain, ensuring complete transparency and traceability. This is crucial for verifying the origins, quality, and processing methods of recycled materials, thus enhancing trust among all parties involved.
- *Smart Contracts:* Smart contracts, self-executing contracts with the terms of the agreement directly written into code, can automate and streamline various processes in the circular economy. For instance, they can automate payments once certain conditions are met, such as the delivery of recycled materials, ensuring efficiency and reducing the need for intermediaries. This automation can provide economic incentives for companies to engage in sustainable practices.
- *Tokenization:* Tokenization can convert rights or assets into digital tokens that can be traded on Blockchain platforms. In the context of CIRCULOOS, this could mean creating tokens for recycled materials, which can then be traded in secondary markets. This not only

creates new revenue streams but also encourages the use of recycled materials, promoting circularity.

- *Decentralized Data Management:* By using Blockchain, CIRCULOOS can manage data in a decentralized manner, reducing the risk of data breaches and ensuring that all participants have access to the same, up-to-date information. This decentralized approach can improve the efficiency of resource management and optimize the use of recycled materials across different companies.
- *Integration with Existing Tools:* Blockchain can integrate seamlessly with existing tools like the Supply Chain Process Orchestration and Execution Tool (SCPO) and the Sustainability Assessment (GRETA Tool). By providing real-time data and ensuring its integrity, Blockchain can enhance the functionality of these tools, leading to better decision-making and more effective circular practices.

Last but not least, since the design of the CIRCULOOS platform follows a end-user and implementation driven approach, there is selection of use cases which are driving the prioritization, implementation, and integration of the aforementioned features as blockchain-based services:

- *Smart Agreement:* Blockchain tokenization of contractual agreements between different involved participants, stating the terms and conditions of the process.
- *Material Verification:* Use Blockchain to verify the origin and quality of recycled materials, ensuring compliance with environmental standards.
- *Smart Recycling Contracts:* Implement smart contracts to automate and ensure transparent transactions within the recycling process.
- *Resource Tokenization:* Tokenize recycled materials to facilitate their trade in secondary markets, creating new business opportunities.
- *Decentralized Collaboration:* Foster a decentralized network where companies can share data and collaborate more effectively on sustainability initiatives.
- *Digital payments:* Through tokenized deposits, and other approaches (eg. stablecoins), digital payments can be implemented in Blockchain, for atomic transactions with real time clearance and settlement.

3.2.2 Circular Manufacturing Capabilities and Software Enablers

3.2.2.1 Stakeholder Engagement and Collaboration (RAMP)

RAMP is a digital platform, which primarily acts as a community building tool. Its objective is to help MSMEs make the transition towards the digitization of their production activities and connect

MSMEs (potentially across industry sectors), as well as MSMEs with providers of innovative digital services that offer new solutions to manufacturing challenges. CIRCULOOS adds one more facet to the set of functionalities offered, that of supporting MSMEs in the implementation of circular practices.

RAMP interacts with its users via the Marketplace, which readily offers several community-building functionalities, like user onboarding (registration, profile display pages) and user interaction (messaging, request to develop a new service). CIRCULOOS will exploit the existing community and functionalities of RAMP to build on top new functionalities that help:

1. to create a registry/ community of MSMEs with the potential to work together in a circular context
2. promote interactions that are more likely to happen (for example connect companies that are geographically closer)
3. implement the vendor onboarding in a systematic way,
4. automate parts of the search for new resources by analyzing the data available in the digital platform.

The RAMP Marketplace will be considered as the main interface of the CIRCULOOS platform for many of the tools developed. Its functionalities will be described in more detail in the second release of the CMRA and the respective deliverables under WP4.

3.2.2.2 Supply Chain Process Orchestration and Execution Tool (SCPO Tool)

The Supply Chain Process Orchestration and Execution Tool (SCPO) delivers two main functionalities: (a) coordinates the activities in situations of multi-actor collaboration by filtering and passing the relevant information to the appropriate recipients and (b) monitors that production processes deliver the value promised (in terms of sustainability performance) by incorporating real-life data to the simulation environment. Its functionality is based on the definition of the underlying process in a BPMN - compatible format. Such process representations will be created or collected for each of the production processes considered in the Circuloos platform. The composition of multiple production processes will be the subject of the application Scenario IV (see Sec. 2.2). In this application scenario SCPO will develop the unified supply chain model (defined by the SCOPT tool - see the following) and will incorporate real-life data to verify that the initially estimated sustainability targets are reached. SCPO will also serve as the orchestrator/ coordinator of different actors, when business level decisions implicate a number of different actors, such as the onboarding of new Vendors/ suppliers. This methodology will build on previous experience gained from the high tech manufacturing business²⁰.

²⁰ Vanderfeesten, I. *et al.* (2019). Developing Process Execution Support for High-Tech Manufacturing Processes. In: Lübke, D., Pautasso, C. (eds) Empirical Studies on the Development of Executable Business Processes. Springer

3.2.2.3 Sustainability Assessment (GRETA Tool²¹)

Sustainability Tool Service Providers offer solutions that enable manufacturers of any size to analyze the environmental, social and economic impacts of their products throughout their entire lifecycle. In the context of the CMRA, the sustainability assessment tool requires access to comprehensive datasets related to material and energy balances, resource consumptions, processing times, transportation distances, prices, geographic location of all the life cycle stages: acquisition of raw/recycled materials, manufacturing processes, maintenance, logistics and end-of-life operations. Leveraging this data in predefined scenarios, the sustainability assessment tool is responsible for generating detailed sustainability assessments for target products and processes, including outputs such as carbon footprint calculations, fossil fuel depletion, environmental toxicity evaluation, and social and economic indicators. The ultimate goal is to equip manufacturers with valuable insights into the true sustainability impacts of their products, especially those revised including circular practices. This empowers them to optimize specific variables, make informed decisions, and ultimately transition towards more sustainable practices in the context of Circular Economy.

3.2.2.4 Supply Chain Digital Twin (SCDT Tool)

The Supply Chain Digital Twin (SCDT) module is developed to create the 3D Digital Twin of Supply chain, production and products. An SCDT, as digital representation of the real environment, is created to visualize the processes and allow the analysis, the data quality control, and the easy reconfiguration of ecosystems towards alternative scenarios creation and sustainability & circularity assessment computation. The SCDT is a decentralized entity, modeling the internal and external states that are related to the supply chain topology of each actor. Each supply chain actor has his own SCDT, implemented either locally or in a cloud setting but maintained locally (by the actor). Each SCDT models the local supply chain topology and it has to communicate with their peers to determine the behavior of the whole supply chain. The goal of the SCDT module is the autonomous evolution of the represented supply chain in order to achieve the real-time visualization of the physical supply chains and data flows while forecasting the reaction of the real environment and the fast comparison between back or estimated data and real-time data.

3.2.2.5 Supply Chain Optimization (SCOPT Tool)

The Supply Chain Optimization (SCOPT) is an AI and Data-driven tool for supply chain optimization in order to ensure the improvement and effectiveness of overall business performance and the costs reduction through manufacturing operations. The SCOPT module extracts the formal models for each actor of the supply chain. The aim of the module is to provide global (i.e. between the factory and the suppliers) and local (within the factory) supply chain optimizations. The module models and analyzes the running processes and the availability of resources, determines the supply chain arrangements, and yields the optimal sequence of the processes.

²¹ <https://www.treasureproject.eu/media/greta-tool-developed-by-supsi/>

3.2.2.6 CV-based system for composition detection

The CV-based System for composition detection is an illustrative enabling capability that falls into the CMRA category of *Reusable tools for MSMEs vertical solution development*. Often, cyber-physical automation service providers are responsible for implementing, deploying, and/or maintaining the solutions that supply chain participants need to streamline and enhance the sustainability of their local production processes. Driven by the needs of the manufacturer, major responsibilities of Cyber-physical System (CPS) based services include sensing the real world and automating physical actions in the manufacturing plant. From the CMRA point of view, CPS based services are the enablers of truly repeatable and traceable manufacturing processes by producing added value data out of the aforementioned physical actions. In the context of the CMRA, added value data are considered those data services and telemetries the CPS contributes to describe and/or allow the real-time monitoring of manufacturer production processes. Potential consumers of the CPS data include other CMRA services such as LCA tools, Supply Chain Digital Twins, and Supply Chain Optimizers.

In the particular case of the tool under discussion, the CV-based technology aims to help manufacturers not only to separate plastic types that until now were discarded as waste but also to incorporate such plastics back into the production process. Therefore, the use case is a model kind to the CMRA purposes since it targets the increment of material flow through a convenient R-strategy and enables a very efficient and narrow circularity loop. As a reusable tool and/or building block of a larger solution, the CV system is designed to operate as a pluggable unit into existing recycling chains.

The need for accurate input data to successfully configure and run the CV-based process is one of the core aspects being addressed for this enabler. The tool must allow the manufacturer to specify the type of plastic in the process under discussion and, based on his/her input, the CV tool shall automatically fine tune its working mode to effectively look for the potential waste resulting from executing the process.

A second core aspect being addressed is the design of convenient features that go beyond the local optimization of a manufacturing process to generate valuable data that can be used by other facilities, added value services, or external supply chain participants. As a first step, the enhancements to the CV-system aim to enhance low level telemetries with a higher level data management layer and convenient interfaces to the CIRCULOOS Local Data Platform. Driven by the requirements of the industrial end-user, the objectives set for the advanced telemetries include:

- Mass of the scraps that is being charged each moment
- The distribution of materials identified in the scraps (percentages)
- Public ID of the company that is producing the scraps
- Stock of scraps available for recyclers along with its chemical/quality features per lot
- Generic workstation metrics for manufacturer data historians such as
 - Number of incidents / stops
 - Production Capacity / Throughput / Material Processing Speed
 - Public ID of the current machine operator
 - Energy consumption parameters

- OEE related parameters (Availability, Performance, Quality)

4 Conclusions

4.1 Design Decisions and Trade-offs

The version of the CMRA presented in this document represents a significant milestone in the CIRCULOOS Project's endeavor to design an open and reusable reference architecture for circular and sustainable supply chains in manufacturing. Throughout the development process, careful consideration was given to various design decisions and trade-offs to ensure the CMRA's practicality and effectiveness. A key focus of the first iteration on the CMRA design and specification has been to enable the creation of innovative solutions that enhance the sustainability, resilience, and circularity of manufacturing supply chains.

Emphasizing generic principles such as reusability, modularity, portability, and scalability, the CMRA aims to go beyond them and deep dive into specific principles that may have direct impact on circular manufacturing performance indicators. This entails contributing with effective designs, reference scenarios, and architecture models to accelerate data-driven solutions to relevant challenges such as reduction of waste, optimization of resource utilization, and promotion of sustainability best practices across manufacturing ecosystems. Additionally, security, trust, and privacy preservation have been integrated as essential cross-cutting pillars into the design. The ultimate aim of the CMRA specification is to be instantiated by functional systems and, therefore, ensuring the integrity and reliability of those systems becomes paramount.

Last but not least, the CMRA aims to be a business case, end-user, and implementation driven specification for circular manufacturing platforms. The requirements, objectives and hosted pilots of the CIRCULOOS Project were the major drivers to achieve that in the current release of the CMRA.

4.2 Implications for related Circular Manufacturing Projects

The current version of the CMRA specification has great focus on the three pilots hosted by the CIRCULOOS Project. In the next release the specification will evolve to become the reference framework for a new series of projects that will implement 16+ circular manufacturing demonstrators across Europe. These projects will be developed and implemented by organizations that are external to the CIRCULOOS project, expanding the applicability of the CMRA to wider areas and application cases within the circular manufacturing domain.

4.3 Future Directions

Next steps will focus on the implementation and deployment of CMRA-based functional systems as well as on conducting extensive pilot testing and validation of the CMRA in diverse real-world scenarios. This will ensure a new CMRA release which is more robust, reliable, and capable of addressing the varied challenges faced by different sectors within the circular manufacturing industry. Extensions to the current CMRA will come in the form of new reference scenarios, architecture concerns, viewpoints and architecture/system views.

Appendix A: CIRCULOOS Platform Demo

The Circuloos Architecture (CMRA) provides the reference for the implementation of the services needed in circular supply chains. The definition of the main building blocks and their implementation as deployable code has been given in Sec. 3.2 highlighting the connection to the data layers from the factory shop-floor. This 'observable' layer provides a generic connector towards existing technology/ infrastructure from the side of the factory to allow for the connection of a number of systems, such as ERPs, sensors, etc.

This section describes one implementation of a potential data source, i.e. a method & tool to digitize production leftovers (waste) - inspired by the HU pilot Use Case (production of leather goods). A very similar problem appears in the wider sector of apparel manufacturing where products are brought together as 3D constructs from the assembly of 2D shapes. The tool described below can be seen as a 'waste digitizer' and serves as an example of how new software applications can connect to the underlying CIRCULOOS platform implementation. The software code for the deployment of the CIRCULOOS platform is available online through the respective github repository²², which contains extensive documentation.

The digitization of 2D outlines is a two-step process: (a) define the outline from the image analysis and (b) translate the outline coordinates as an NGSI entity and upload to the data platform.

Leather board outline

The manual process of producing leather goods often generates leftovers with irregular shapes that are very difficult or impossible to digitize by hand. To solve this time-consuming task and enable the digitalization of these leftovers so they can be added to the CIRCULOOS platform, ED developed a computer vision software to trace the outline of the leftovers.

The design goals of the software were to create a simple, easy-to-use interface that does not require any specialized camera. Users can utilize any modern color camera to take a picture of the leftover, provided it is placed on a white background with at least one Aruco marker. The photograph is then uploaded to the web-based tool, which transforms it into an NGSI-LD compatible JSON file.

To achieve the digitalization of the leftover, several functions of the OpenCV library were utilized. These functions calculate the outline of the leftover and transform it into a polygon. Aruco markers, a widely used technique in computer vision, are employed to calibrate the dimension of the camera pixel. By understanding the pixel dimension in millimeters (mm) and the coordinates of the polygon outlining the leftover, the software can calculate the real dimensions of the leftover. The output of this procedure is a 2D coordinate of the outline encoded in GeoJSON format, using decimal WGS84 representation in meters.

²² <https://github.com/european-dynamics-rnd/circuloos-data-platform>

After the digitalization of the outline is complete, users need to add all the required entities necessary for the creation of the digital twin of the leftover. These entities include attributes such as leather type, brightness, and hardness. Once all the necessary fields are completed, the software generates an NGSI-LD JSON file. This file can be sent to either the local or the central instance of the CIRCULOOS platform.

This solution efficiently addresses the challenge of digitizing irregularly shaped leather leftovers, making the process more accessible and compatible with the CIRCULOOS platform. By leveraging common technology and user-friendly design, it ensures that the integration of leftovers into the digital platform is both straightforward and efficient.

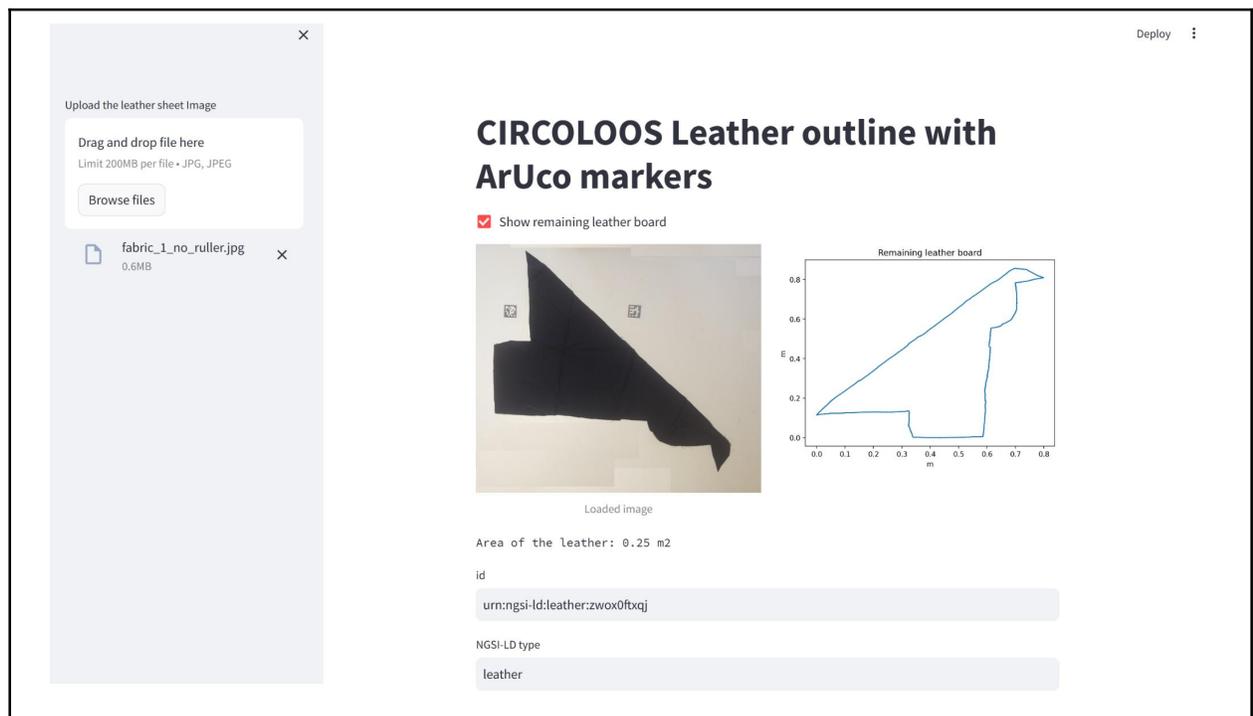


Figure A1. UI for outline extraction from 2D images

Once the numeric data has been extracted from the image, it is automatically converted to an NGSI-json file and posted on the Context Broker for storage in the data platform. The input to this convertor is any type of CSV (Comma Separated Value) file.

CSV to Orion-LD agent

The CIRCULOOS Platform utilizes FIWARE components and is compatible with the NGSI-LD specifications. An initial development of the [CIRCULOOS Data model](https://github.com/konstantinosGombakis/CIRCULOOS_Data_model)²³ has been carried out and is based on the [Smart Data Model](https://smartdatamodels.org)²⁴s extending their vocabulary to include additional entities, which for the example of the specific Use Case are the leather characteristics. The process of translating the numeric data extracted from the 'waste digitizer' to the format required by the Data model is

²³ https://github.com/konstantinosGombakis/CIRCULOOS_Data_model

²⁴ <https://smartdatamodels.org>

done automatically by the csv to orion-ld agent. Figure A2 depicts the UI that employs the ngsi-translator to convert the data to the appropriate format and Figure A3 & A4 present excerpts of the Smart Data Model developed in CIRCULOOS for the new entity 'leather component'.

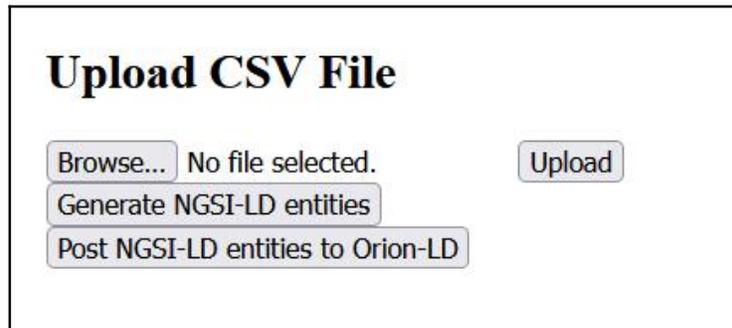


Figure A2. CSV to Orion-LD agent feature (Snapshot of the Web interface)

1	id	type	observedat	origin	color	surfaceSize	thickness	thickness_unitCode	tannedProcess
2	urn:ngsi-ld:circuloos:leather:IDAS1313	leather	0	vegan	black	2	0.3	MMT	vegetable
3	urn:ngsi-ld:circuloos:leather:IDAS142	leather	2024-01-01T01:00:00Z	vegan	red	5	0.4	MMT	vegetable

Figure A3. Extract of an input file (csv format)

```
{
  "id": "urn:ngsi-ld:leather:IDAS1313",
  "type": "leather",
  "@context": [
    "http://circuloos-ld-context/circuloos-context.jsonld"
  ],
  "origin": {
    "type": "Property",
    "value": "vegan",
    "observedAt": "2024-05-23T13:11:36Z"
  },
}
```

```
"color": {  
  "type": "Property",  
  "value": "black",  
  "observedAt": "2024-05-23T13:11:36Z"  
},  
"surfaceSize": {  
  "type": "Property",  
  "value": "2",  
  "observedAt": "2024-05-23T13:11:36Z"  
},  
"thickness": {  
  "type": "Property",  
  "value": "0.3",  
  "unitCode": "MMT",  
  "observedAt": "2024-05-23T13:11:36Z"  
},  
.....  
}
```

Figure A4. Part of the generated NGSI-LD JSON file

CIRCULOods



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101092295. The herewith information reflects only the author's view. The European Commission is not responsible for any use that may be made of the information herewith included.