Product Passport through Twinning of Circular Value Chains

Deliverable 1.5

CRIS Requirements and specifications v1

WP1: Digital circular value chain framework

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Executive Summary

This document is the first version of deliverable D1.5 "CRIS Requirements and specifications" and describes the activities carried out in Task 1.5 for the specification of Circular and Resilient Information System (CRIS) to support the pilots in their digital and circular transition. Additionally, it provides an overview of the results achieved in all tasks of WP1, showing how they will be used and integrated in CRIS to provide a unique solution that fulfil the user's needs.

The adopted methodological approach relies on consolidated software development practices, starting from an in-depth analysis of the customer's (pilot) needs. The enhanced pilot stories constitute the basis for requirements elicitation. The derived requirements allow to draft the first version of the architecture, and the specification of its components. More specifically, each pilot to-be scenario has been described specifying the intended use of the different modelling tools (at supply chain level as well as at internal process level) and different services (analytics, optimisation simulation, etc.) which will be provided within WP2.

This exercise allowed to derive the functional and non-functional requirement for CRIS requirements leading to the system architecture. The architecture has been described in terms of its internal components and its relationships with tools and services to be implemented in WP2.

For completeness and to provide a comprehensive view of the Plooto technical offerings, each tool and service is described.

Finally, the deliverable presents the approach for the implementation of the Digital Product Passport (DPP), defining the data structure and the procedural aspects and how these are implemented using the different features provided by CRIS.

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Acronyms and Abbreviations

Acronym	Description
API	Application Programming Interface
BSC	Balanced Score Card
CPW	Citrus Peels Waste
CPWW	Citrus Peels Waste Water
CRIS	Circular and Resilient Information System
DA	Digital Asset
DPP	Digital Product Passport
DSP	Data Space Protocol
DT	Digital Twin
EDC	Eclipse Dataspace Component
GBA	Global Battery Alliance
HIR	Hierarchical Inheritance Registry
HTTPS	Hypertext Transfer Protocol Secure
IAM	Identity Access Management
IDSA	International Data Space Association
IMF	Information Modelling Framework
LCA	Life Cycle Assessment
MFN	Material Flow Network
PDCS	Product Circularity Data Sheet
PM	Permanent Magnet
PMS	Process Modelling and Simulation
SBSC	Sustainability Balanced Scorecard
SRM	Secondary Raw Material
SSN	Secure Socket Network
SSO	Single Sign-On
REE	Rare Earth Element
REO	Rare Earth Oxide
R&D	Research and Development

Acronym	Description
UAV	Unmanned Aerial Vehicles
UI	User Interface
WEEE	Waste Electric and Electronic Equipment
WS	Web Service

1 Introduction

Climate change introduces fresh risks and amplifies pre-existing vulnerabilities in communities globally, posing existential challenges concerning human health and safety, overall quality of life, and the pace of economic growth. The Fourth National Climate Assessment[1], published in 2018, alerted that if we do not curb greenhouse gas emissions and start to adapt, climate change could seriously disrupt the U.S. and global economy.

This requires a profound change in mentality that not only promotes the adoption of virtuous practices (e.g., Reduce, Reuse, Recycle), but also influences the very economic fabric of our society. The prevailing economic paradigm must shift from pure profit-centric models to more holistic ones where economic strategies are intricately woven with sustainability goals. Circular economies and the recognition of waste as a resource are pivotal in this transformation.

Embracing circularity is integral to this transformation. The traditional linear model, where resources are extracted, used, and discarded, is no longer sustainable. Circular Economy promotes the continual use, recycling, and repurposing of materials, minimizing waste and environmental degradation.

Circularity thus, provides a unique opportunity to transform the climate crisis into an opportunity for business and economic growth. The adoption of innovative technologies and sustainable practices that link environmental sustainability to economic viability can support enterprises in the circular transition fostering economic growth while mitigating environmental harm.

In line with the above considerations, Plooto aims to provide a *Circular and Resilient Information System that enables waste reduction and end-to-end traceability of Secondary Raw Materials*. Plooto will provide innovative interconnected digital services that, based on digital transformation strategy tailored to process industries, allow: 1) the administrative management of circular supply chains, 2) the monitoring and tracing of materials and used resources throughout the whole supply chain, and 3) can produce certifications of materials and products (Digital Product Passport).

1.1 Purpose and Scope

This deliverable provides an overview of the technologies and tools that will be developed and integrated into the Plooto Circular and Resilient Information System (CRIS), and specifies the characteristics of CRIS architecture, identifying the main components and their connections.

Although the main focus is on the architecture, the document presents also the initial technical results achieved in WP1. Additionally, it describes the holistic user-centred methodological approach where the description of pilot scenarios was used to 1) identify the needs of the pilots,

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[1] https://nca2018.globalchange.gov

2) derive the initial set of technical requirements, 3) specify – for each pilot- the use of the different horizontal services, and 4) design the architecture.

1.2 Relation with other deliverables

The CRIS architecture design proposed in this document set the foundations for the technical implementation and integration of the different components and services.

It takes as input information concerning the pilots' scenarios and goals from D1.1 Plooto Methodological Approach and Business Cases Specifications and information related to relevant KPIs from D1.3 Sustainability Balanced Scorecard Framework.

The deliverable provides main contributions to WP2 and WP3 (Figure 1), and indirectly to WP4.

In WP2, the architecture diagrams, the initial set of requirements, and the pilot specific data structures, set the stage for the different services that will be implemented and documented in *D2.2 Plooto complete suite of services*, while the described approach to Data Spaces will support the realisation of the Row Material recovery and waste Data Space that will be documented in *D2.1 RM-recovery and waste Data Space.*

In WP3 the deliverable provides information for the implementation of the Digital Product Passport (D3.1), for Plooto balanced scorecard (D3.3) and for CRIS integrated platform (D3.2).

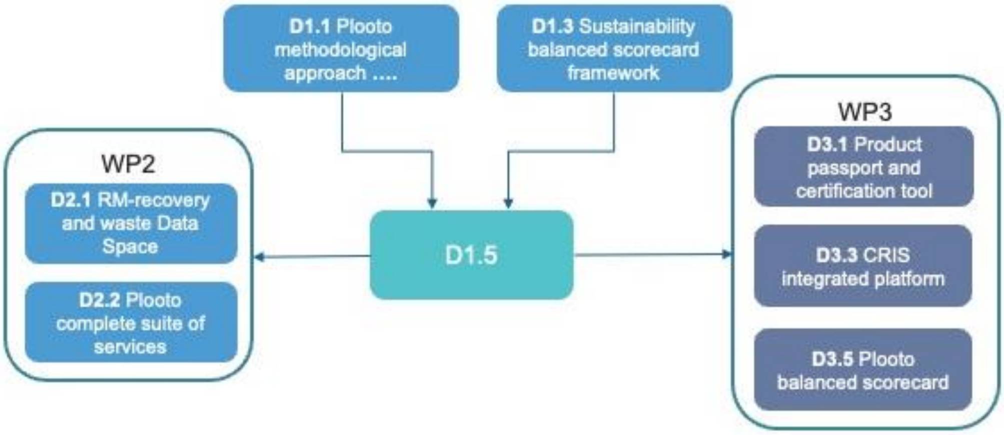

Figure 1: Relations with other deliverables

Additionally, the deliverable outlines the boundaries and features of the pilots' to-be scenarios, therefore it has an indirect relationship with WP4.

1.3 Structure of the document

The document is structured as follows:

- **Section 2** describes the adopted methodological approach.
- **Section 3** describes the user needs and derives functional and non-functional requirements describing the platform.

- **Section 4** introduces the Information Modelling Framework (IMF) and describes how it is used for semantic interoperability and formalization of the DPP.
- **Section 5** Introduces the proposed architecture and describes the main components, services, and tools that will be integrated and made available to the pilot users.

2 Methodological approach

Since the beginning of the project, WP1 involved the pilots and all technical partners from WP2 in active discussions to precisely define the scenarios that will be implemented in Plooto. The pilot stories have been described in collaborative living documents which detailed the operational and technical needs as well as the main aspects to be monitored and evaluated in the pilot processes. Such documents provided a solid basis from which to define the methodological approach to draft CRIS architecture and provide a concrete innovation that supports the digital and circular transition fulfilling the needs of the industry. The adopted approach consists of an iterative process represented in Figure 2.

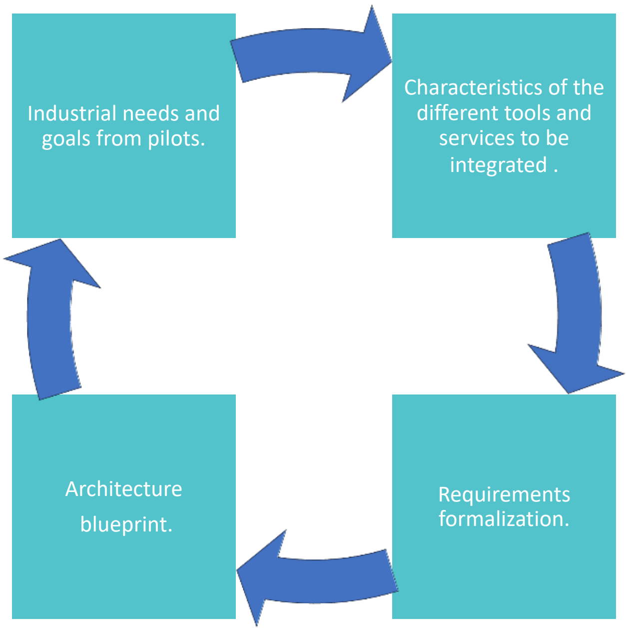

Figure 2: Methodological approach

Define Industrial needs and goals from pilots: consists in the formalization of to-be scenarios focusing specifically on the goals that the pilot wants to achieve and which services or tools will be useful to achieve the goals.

Understanding the characteristics of the different services and tools to be integrated: consists in defining how the different services (e.g., analytics, optimization, simulation, etc.), tools (e.g., PMS, SBSC), and technologies (e.g., IDS connectors, Blockchain), that Plooto will integrate, will be used within each pilot.

Formalize needs and technical characteristics into requirements: a textual analysis has been carried out on pilot specific living documents to identify the required *behaviours* (functional requirements), the constraints, required performance, and needed services (non-functional requirements) that the platform should provide. Refer to Section 3.2 for further details.

Draft the architecture blueprint: this activity is based on consolidated best practices, standards, and the elicited requirements. Based on the draft architecture, an initial integration approach has been proposed (see Section 5.7).

3 User needs and requirements elicitation

Plooto aims to provide the environment for stakeholders to manage the operational aspects of their collaboration and to monitor the entire supply chain and internal processes, still safeguarding privacy, ownership and confidentiality. The goal is to model the whole supply/value chain, the internal processes, and to obtain ways and metrics to monitor a given process and to manage the exchange between the different actors in the supply chain.

For the scope of this deliverable, the information concerning the pilot stories has been synthesised to better focus on the features that the platform should provide. The following sections in this chapter, provide an overview of the three pilots (derived from the living documents mentioned before). Each section reproduces the working process carried out that can be summarized as follow: design the to-be scenarios, design the representational process models, define the scope of each service in relation to the pilot, model the processes - and eventually the supply chain - in terms of DTs.

Besides a necessary step to draft CRIS architecture, the work done provides valuable insights for the tools and services that will be implemented in WP2, and to design the ICT framework and usage scenarios encompassing all needed features and foreseen artefacts (e.g., DPP).

3.1 Pilot stories

3.1.1 Italian pilot

The use of Carbon Fiber Reinforced Polymer (CFRP) composites is rapidly increasing due to their peculiar characteristics (lightness, strength, durability, versatility), which open the way to endless applications in different domains, such as automotive, aeronautics, maritime and leisure. Before being used in production, CFRPs need to be stored at low temperature to avoid their degradation. The production waste consists of *scraps of cured material* coming from the cutting operations or *partial rolls of uncured material* that have reached the expiration date. This waste has to be disposed, due to the lack of recycling /reuse alternatives, representing both an environmental challenge and an economic loss for the manufacturer. Composite materials are considered special waste requiring dedicated and costly disposal procedures. Disposal fees can range from 250 to 300€/ton and increase exponentially if the waste is considered hazardous, as in the case of uncured prepregs.

The Italian pilot aims to identify best practices and procedures to extend the usability of CFRPs. Through the establishment of a virtuous circle among key partners operating in the sector, the goal is to recover scrap and expired material, re-qualify it to extend its shelf-life, allowing the use of the reconfigured material in other applications.

Specifically, the supply chain, which is graphically represented in Figure 3, involves 4 partners: HP Composites (HPC), Cetma Composites (CC), Cetma, and Accelligence (ACCELI).

HPC is a world leader in the design and production of CFRP components for the aerospace, automotive, motorsport, naval, industrial and design sectors. The amount of waste from the production line amounts to approximately 30 tons of uncured prepreg scraps per year.

CC is an innovative SME whose current business includes the production and sale of CFRP composite material products for sport, furniture and leisure sectors.

CETMA is a Research Centre with extensive expertise in materials engineering, recycling, computer engineering and industrial design.

ACCELI is a Cyprus-based company, engaged in cutting edge R&D activities on Unmanned Aerial Vehicles (UAVs), haptics and other robotic activities. ACCELI manufactures custom UAV prototypes, with different characteristics based on customer's requirements.

Pilot scope: Recover scrap and expired material, re-qualify it to extend its shelf-life, allowing the use of the reconfigured material for the production of drone parts based on ACCELI specifications. Such products should be characterized by high performance, reduced cost and lower environmental impact.

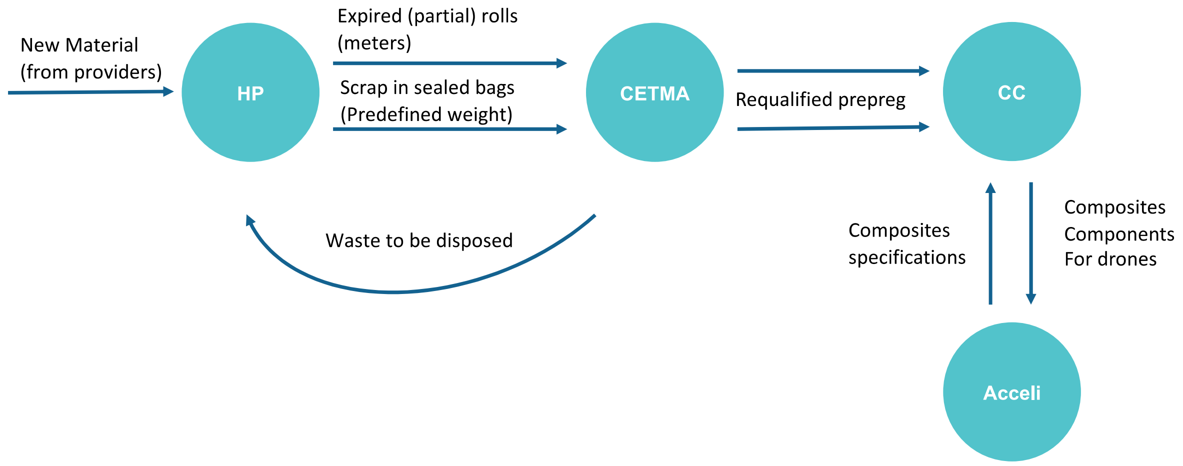

Figure 3: Italian pilot supply chain

The overarching objective of the pilot is to drastically reduce the amount of CFPRs waste that ends up in landfills and to transform the waste into a sort of Secondary Raw Material (SRM) to be used in the production of new products.

This will be achieved by developing practices and guidelines that increase CFPR shelf-life (CETMA) through the definition of requalification processes. The requalification process determines the new process window for the material (working temperature and pressure). The requalified CFPR can then be used for new productions.

3.1.1.1 Needs

Process modelling and simulation

Italian pilot ecosystem comprises a linear four-actor value chain (Figure 4).

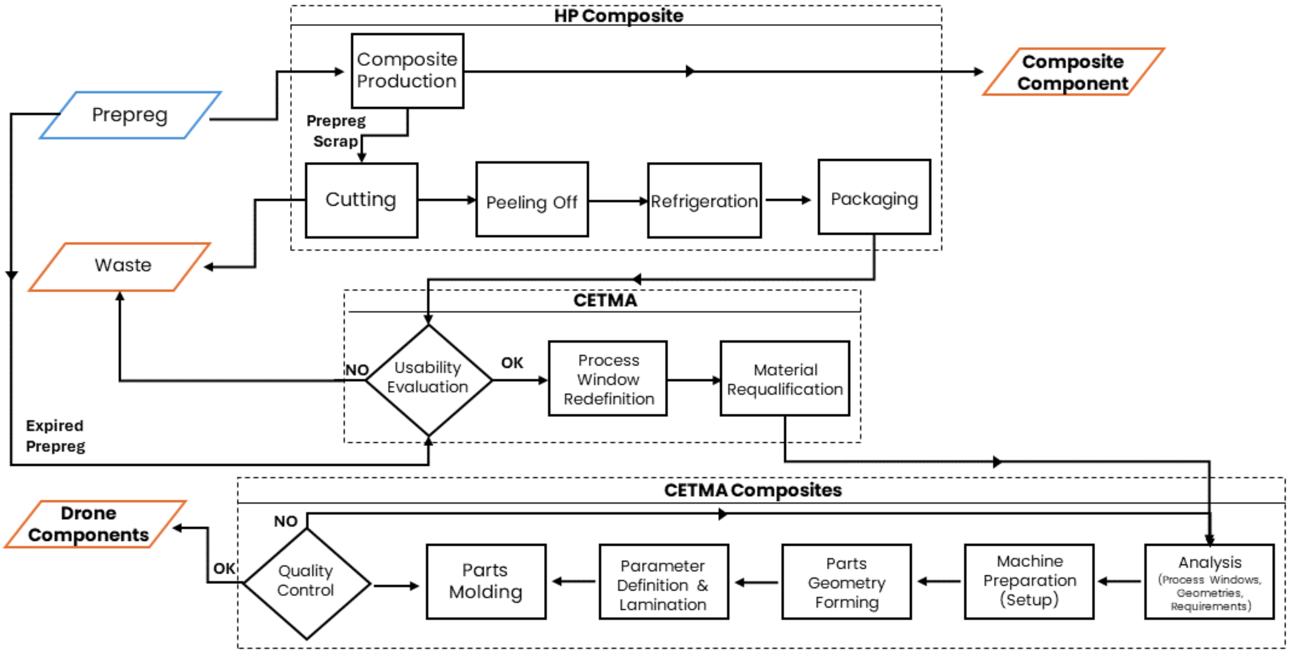

Figure 4: Italian pilot: value chain and process model

Scope: The primary focus of PMS is to develop process models for (a) prepreg scrap management (HPC), (b) usability evaluation and requalification procedures (CETMA), (c) parts constructions and quality control (CC), on alignment with the requests of end-products (drone parts) specifications and properties (ACCELI).

Impact: The PSM tool significantly models the entire value chain by offering a comprehensive and detailed representation of processes, accommodating various educational levels and specializations. It effectively maps out inputs, outputs, physical connections, interactions, and the flow of materials, data, and energy within the value chain. Acting as a crucial interpreter, PSM interacts with analytics and optimization services. It incorporates analytics-driven insights to refine model accuracy, aiding the optimization tool in delivering efficient and robust solutions. As an essential component of the Plooto suite, it plays a pivotal role in the decision-making processes. PSM enables tailored monitoring, investigation, identification, and evaluation of diverse scenarios, including root-cause analysis, what-if analysis, and comparative assessments. Its design as a reusable, expandable, adaptable, updatable, replicable, and API-available tool that reduces the overall effort and enhances its integration with associated services, underscoring its versatility and effectiveness in varied applications.

Data Requirements: A detailed analytical description of the stages involved in these processes and of the available equipment (basic and, or auxiliary) along with their quantitative characteristics (setup times, processing duration, maximum equipment capacities, transfer times, initial stock levels, demand etc.) is required. Additionally, it involves examining the potential use of primary inputs (requalified prepreg and prepreg scraps), and secondary inputs (e.g. energy consumption), within these processes.

Analytics

In the realm of modern manufacturing, data-driven analytics plays a pivotal role in enhancing efficiency, quality, and decision-making processes. In the Italian pilot, the analytics specifically focuses on the evaluation and classification of prepreg material – a critical component with a limited lifespan depending on the history of storage conditions.

The drone production pipeline relies on prepreg material as a fundamental component. Prepreg material, being perishable, requires careful evaluation (based on measurements) to ensure optimal utilization in the manufacturing process. Data-driven analytics has been envisioned to be integrated into two key junctures within the pipeline: the assessment of uncured prepreg and the categorization of cured prepreg.

In the initial scenario, data-driven analytics is employed to evaluate the suitability of uncured prepreg material for the curing procedure. This application will use a classification algorithm designed to make informed decisions based on data inputs. The primary variables considered in this classification algorithm include:

- **Storage History:** A time series of temperature and pressure data are available for each batch of prepreg material. This historical data provides critical insights into how the prepreg material has been stored, enabling the algorithm to make informed predictions.
- **External Data Sources:** Complementing the internal data are external data sources that can further enrich the classification process. These may encompass weather conditions, humidity levels, or other factors that could influence prepreg quality.

Time series data will be pre-processed in a way that relevant derived features will be extracted and used in feature vector for classification. The classification process for uncured prepreg material can manifest in two primary scenarios:

- **Binary Classification:** The algorithm classifies the material into two distinct categories - 'positive' and 'negative.' A 'positive' classification implies that the material is suitable for the curing procedure, while a 'negative' classification suggests otherwise. If algorithm is successful, it could partially omit the need for testing of certain materials (e. g. those batches that will be classified as waste after the physical testing).
- **Multiclass Classification:** In this scenario, the algorithm expands its categorization beyond a binary system, drawing insights from existing literature. Multiple prepreg classes are defined based on their specific characteristics and attributes, enabling a more

nuanced evaluation. Such classification could even be performed with additional measurements data.

Data-driven analytics is equally beneficial in the **classification of cured prepreg material**. Similar to the uncured prepreg scenario, this phase employs classification algorithms guided by literature-based insights. The goal is to categorize the cured prepreg into classes that reflect its properties and quality. All analytics scenarios will later be used either for process modelling or optimization purposes.

We estimate that with leveraging machine learning and data analysis techniques, this approach can enable more efficient decision-making, enhance material utilization, and contribute to the overall efficiency and quality of drone production.

It is important to acknowledge the risk that **classification algorithms may face limitations**, especially when dealing with stochastic environmental factors or incomplete data (e. g. some relevant feature has not been measured). These issues should be also considered within the Italian pilot. Stochastic factors, such as abrupt temperature or pressure fluctuations or way of handling of materials, can introduce noise and data inconsistencies, making it challenging for algorithms to accurately assess prepreg material quality. Additionally, the presence of stochastic elements can amplify uncertainty in the classification process, making it difficult to distinguish between material affected by environmental fluctuations and genuinely unsuitable material.

Human expertise should complement machine learning (and machine learning experts) in order to mitigate these issues. Domain experts can provide valuable insights and judgment in cases where classification results are uncertain or data is incomplete, suggesting improvements of the modelling approaches.

Optimization

Scope: The optimization model is designed to enhance the efficiency of HPC, CETMA, CC, and ACCELI within the context of their value network. Specifically, it *decomposes each order originating from ACCELI into a series of subproblems*, corresponding to the diverse CFRP components required for drone construction. For every individual part, the optimization service *dynamically generates a network that encapsulates various process states,* illustrating alternative pathways for the production of the specified component within the broader value network. The service's output comprises the *optimal path/flow within this constructed network, along with the selection of optimal operating scenarios for each stage of processing*. The overarching goal of the optimization process is to *minimize the total energy consumption within the value network*. This approach not only streamlines the production of CFRP parts but also contributes to a more sustainable and energy-efficient operation across the entire value network.

Impact: The growing utilization of CFRP has raised environmental concerns, particularly regarding the disposal of waste composites. Failing to appropriately manage the disposal or repurpose these composites poses significant environmental risks and results in the squandering of a valuable resource. Consequently, it is imperative to devise efficient technologies for recycling waste CFRP composites, aligning with principles of environmentally friendly and sustainable development. While analytics offers insights into the connections between alternative requalification strategies and cured prepreg, the optimization process orchestrates the entire workflow across the value network. This comprehensive approach yields *solutions that are optimal from a global perspective, ensuring efficiency and sustainability throughout the entire process.*

Data Requirements: The optimization service is intricately dependent on data sourced from experts within the value network, analytics, and simulation. This critical data encompasses *mappings that establish connections between diverse requalification processes, linking various classes of uncured prepreg to their corresponding requalified uncured prepreg counterparts*. Likewise, we need access to *mappings between requalified uncured prepreg and cured prepreg, guided by alternative process window options.* Possessing these mappings is crucial as they dynamically inform the generation of alternative operating scenarios for each process. Furthermore, it is imperative to have access to data detailing the *energy requirements for each alternative process stage and operating scenario.* This information is indispensable for our comprehensive analysis, ensuring a thorough understanding and optimization of the overall system.

Supply chain and internal process(es) models

The *DT supply chain model*, involves all pilot partners as depicted in Figure 5.

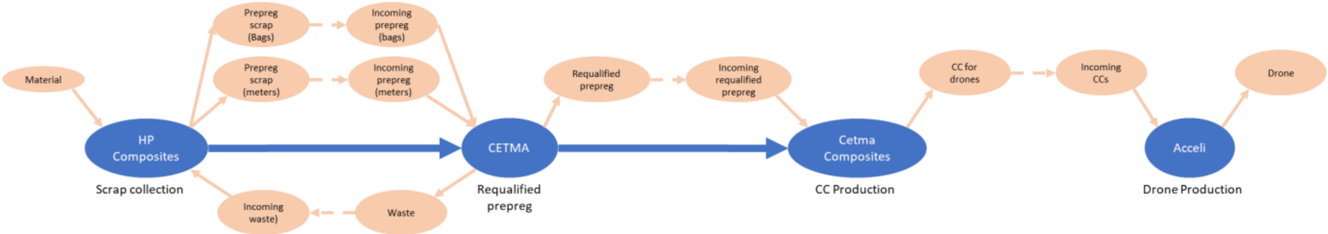

Figure 5: Italian Pilot DT supply chain model

Table 1: Italian pilot key processes and roles

Partner	Process	Roles
HPC	Scrap and expired prepreg collection	Starts the supply chain, collects scrap and expired prepreg from their industrial production. Waste material is sent to CETMA for requalification
CETMA	Waste to requalified material	Transform waste into requalified material to be used in production

Partner	Process	Roles
CC	Requalified material to CCs for drones	Used requalified material from CETMA to produce components for Drones (based on specifications from ACCELI).
ACCELI	CCs to drone production	Receives composites components to be used in production of drones.

The supply chain will be modelled using corresponding features presented in the Digital Twin modeller described in Section 5.4.2. The configuration of the supply chain concerns the data to be exchanged among the parties (Task 2.1).

The DT process models will be based on the processes described in Figure 4, will concern essentially the production process in Cetma Composites, and will focus the performance and energy consumption of the production.

3.1.2 Greek Pilot

ASPIS is a company based in Argos, Greece that produces a great variety of fruit juices and fruit purees, aromas & oils, fruit preparations and canned products. Currently, it operates two processing plants in two different regions in Greece, namely at Argos and Irinoupoli.

The Greek pilot involves the processing plant at Argos. This plant processes citrus and deciduous fruits and vegetables to produce fruit juices and purees, citrus oils & aromas, fruit preparations, mixtures, and animal feed from citrus peel.

The pilot focuses on processing the waste stream from the main production line (orange juice) to obtain additional products - that could be relevant in other sectors - and significantly reduce waste. The main aim is to optimise the process in relation to energy consumption.

The processing of the solid phase of the waste generates several secondary products, such as various types of molasses, citrus silage and pellets that are used for the production of animal feed. From an economic perspective, molasses is the most significant secondary product, due to the high value, while the other two (sludge and citrus silage) represent interesting products that can be reused and ultimately enhance circular economy.

Similarly, the processing of the liquid phase of the waste generates additional valuable products, such as orange oil and various aromatic compounds (e.g., terpene and d-limonene), which could be of interest to other sectors (e.g., pharmaceutical).

The aforementioned products from the processed waste are very interesting from a circularity perspective, because their valorisation facilitates the overall waste reduction, while creating new business opportunities.

Another interesting aspect concerns the use and dispose of produced wastewater. The wastewater stream from the solid phase is recycled and used to wash the fruit to be processed, while the stream from the liquid phase represents the final wastewater (CPWW) that is free from hazardous contaminants or sludge and can be either disposed to the environment or used in other products (i.e. fertilizers) without further processing.

The Greek pilot aims to demonstrate how the reduction of energy consumption within a single process line can be achieved by data analytics and process optimization. Moreover, the environmental benefits of this optimization will be highlighted using Life Cycle Assessment (LCA) as a validation tool. Regardless, this pilot represents a very interesting case from an environmental point of view.

Figure 6 depicts the Greek pilot value chain and offers a synthetic overview of the main production outcomes. The value chain is internal to ASPIS with no collaboration with 3rd parties (either providers or customers). In Figure 6, the internal process has been synthetised to offer an overview of the main outcomes, but it is fully described in Figure 7.

Pilot scope: Optimize the energy intensive processes of the waste valorisation processing line that produces animal feed components of high nutritional value, aiming at an improvement of the environmental footprint and a reduction of the energy demand.

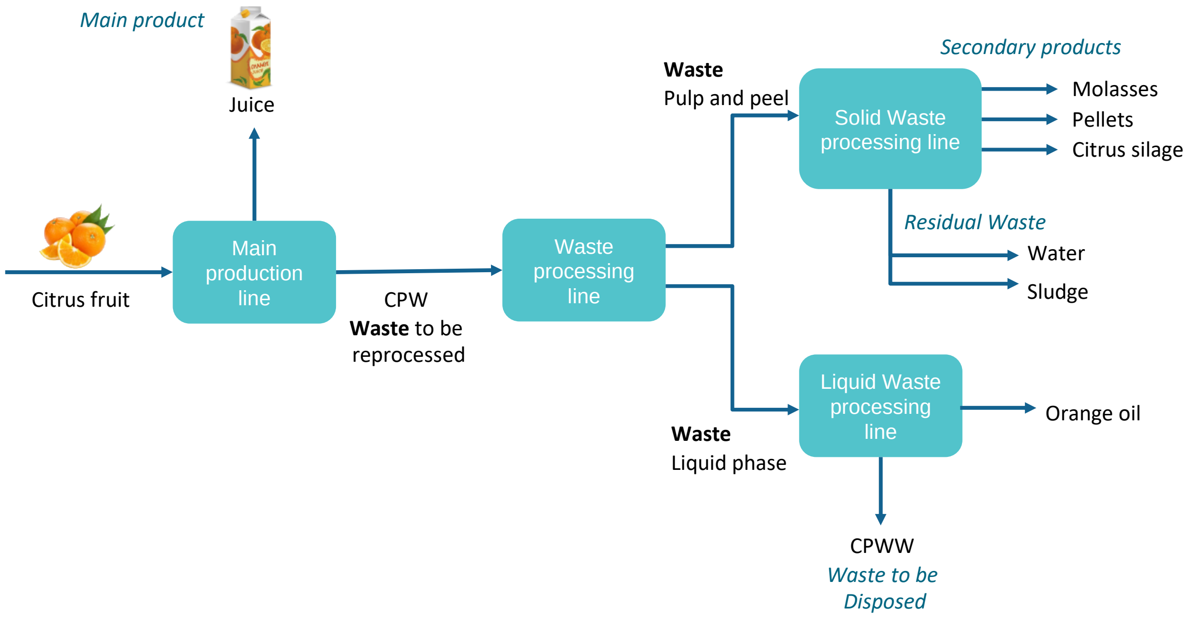

Figure 6: Greek pilot value chain

The overarching objective of the pilot is to significantly reduce the amount of energy consumption within the waste valorisation processing lines. This decrease in the energy consumption will be highlighted via the LCA analysis be achieved using the outputs of the optimization provided by the relevant partners. Moreover, Plooto's impact can also be highlighted by the residual wastes of the processing line, which will be water free from any hazardous contaminants and sludge that can either be disposed in the environment or be utilized in other terms (i.e. fertilizers).

3.1.2.1 Needs

Process modelling and simulation

The Greek pilot pertains to a linear single-actor (ASPIS) value chain (Figure 7).

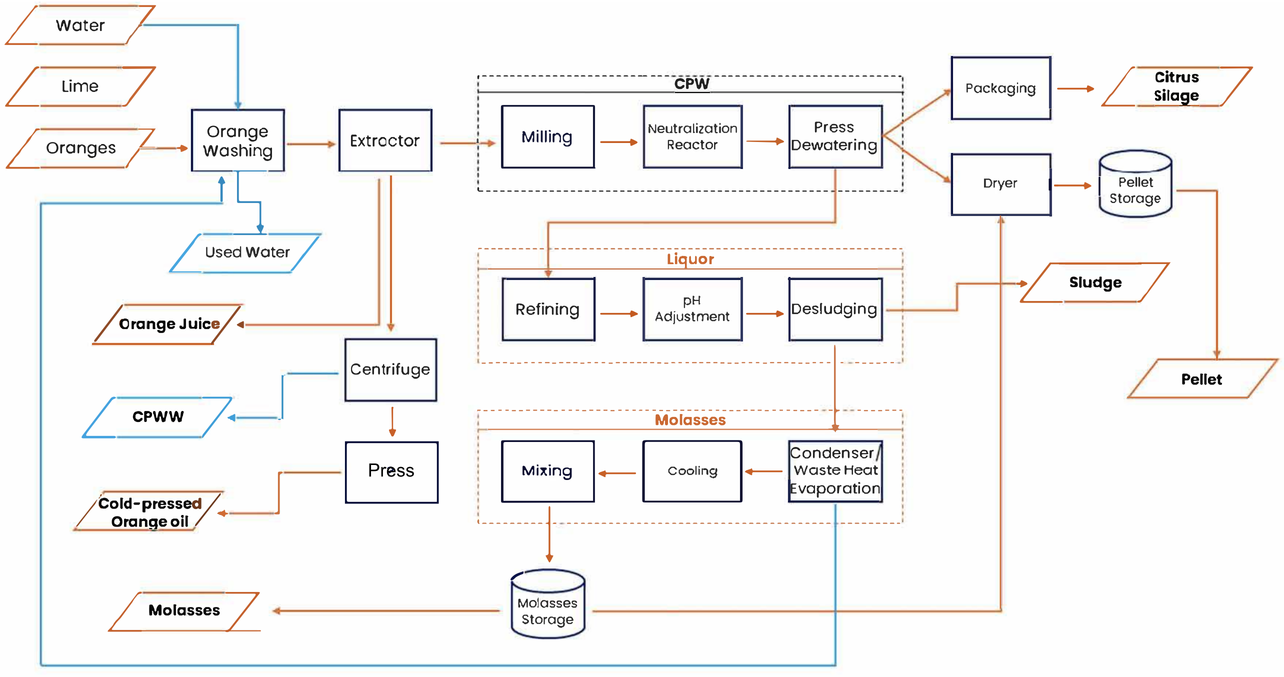

Figure 7: Greek pilot process model

<u>Scope</u>: The PMS is responsible for developing the process model describing (a) the main production line regarding citrus management and juice extraction, (b) the wastewater and residuals' management coming from the primary production activity, as well as (c) the production of molasses, citrus pellets, sludge, orange oil, and citrus-processing wastewater (secondary products).

<u>Impact</u>: The PSM tool models the entire value chain by offering a comprehensive and detailed representation of processes, accommodating various educational levels and specializations. It effectively maps out inputs, outputs, physical connections, interactions, and the flow of materials, data, and energy within the value chain. Acting as a crucial interpreter, PSM integrates analytics and optimization services. It incorporates analytics-driven insights to refine model accuracy, aiding the optimization tool in delivering efficient and robust solutions. As an essential component of the Plooto suite, it plays a pivotal role in decision-making processes. PSM enables tailored monitoring, investigation, identification, and evaluation of diverse scenarios, including root-cause analysis, what-if analysis, and comparative assessments. Its design as a reusable, expandable, adaptable, updatable, replicable, and API-available tool reduces the overall effort and enhances

its integration with associated services, underscoring its versatility and effectiveness in varied applications.

Data Requirements: A detailed description is fundamental to accurately represent the subsequent stages of the production processes. This should encompass a thorough breakdown of each stage, explaining the specific tasks and the relevant equipment/processes followed. Besides, the quantitative attributes associated with each stage are vital to be defined on detail to enable the proper execution of the simulation process.

LCA

Scope: The primary goal of the pilot case is to minimize energy consumption during the processing of Citrus Peels Waste (CPW) derived from the primal production line. Simultaneously, the Citrus Peels Waste-Water (CPWW) will undergo re-processing within the production line, aiming to diminish the requirement for fresh water. Ultimately, our vision is to evaluate the improvement of environmental sustainability achieved by the optimization of the waste valorisation process line.

Impact: The process is characterized by the continuous flow of CPW, necessitating treatment with minimal energy consumption. This is imperative due to stringent environmental constraints, particularly the risk of soil and water pollution associated with uncontrolled disposal. The impact of the LCA analysis will be the overall evaluation improvement of environmental sustainability achieved by the optimization of the waste valorisation process line.

Data Requirements: A demand exists for gathering all relevant data regarding each process. These data include raw and auxiliary materials mass flows, energy and water consumption, wastewater and solid wastes generated mass flows and each type of animal feed produced during the processes.

KPAD will utilize data obtained within the processing line to perform the LCA analysis.

Analytics

Scope: Analytics is implemented along the main objectives of the pilot case, namely, to assist in minimizing the energy consumed for waste processing and help increase the value extracted from the by-products of the process. To this end, the analytics platform will examine the machine operations, heating and cooling systems, and periodicity of energy consumption. Regarding by-products, we will identify the temporal and quality patterns in their production and classify them according to relevant dimensions. Additional information based on anomaly detection or unsupervised learning may be generated.

Impact: The impact of the analytics, which enables decision-making and optimization, is expected to have both a financial and environmental impact. Through repurposing by-products, and lowering the energy consumption, a significant environmental benefit will be realised. Also, from a financial standpoint, the optimizations supported also by analytics, will provide a financial incentive for the industry.

Data Requirements: In order to provide valuable analytics, detailed historical data is required. Regarding Energy consumption, the data needed refer to the time, type, and quantity of energy consumed in different stages on the production line. This could be machine configurations and run-time, as well as sensor data. Moreover, analytics would need the quantitative and qualitative characteristics of the by-products, while also additional insights from detailed manufacturing process data from sensors, and market data may be considered.

Optimization

Scope: The *primary goal* of the pilot case is to *minimize energy consumption during the processing of Citrus Peels Waste (CPW) derived from the primal production line*. Simultaneously, the Citrus Peels Waste Water (CPWW) will undergo re-processing within the production line, aiming to diminish the requirement for fresh water. Ultimately, our vision is to achieve the cost-effective reutilization of waste, emphasizing the reduction of energy consumption, and to obtain additional by-products with potential applications across various sectors.

Impact: The process is characterized by the continuous flow of CPW, necessitating treatment with minimal energy consumption. This is imperative due to *stringent environmental constraints*, particularly the risk of soil and water pollution associated with uncontrolled disposal. Beyond environmental considerations, there is an economic dimension to the process, as the treatment of CPW can result in the generation of secondary by-products that may contribute additional revenues. The optimization model is centred on enhancing the overall flow of Citrus Process Waste (CPW) within the waste production line to *generate high-nutrient cattle feed, including molasses, citrus silage, and pellets.* The waste flow undergoes distinct processes for the separation of liquid and solid components, supplemented by the injection of additional ingredients (e.g., lime) to *meet exact specifications for cattle feed*. This systematic approach ensures the production of cattle feed with optimal nutritional content by leveraging the efficient management and transformation of waste streams through various stages of processing.

Data Requirements: A demand exists for each type of animal feed, and it is imperative to meet this demand efficiently. Accurate i*nformation pertaining to individual requirements, ingredient quantities, and specifications for cattle feed is crucial at all blending points*. Furthermore, for pellet production, understanding the percentage composition of solid elements and molasses is vital. Additionally, *comprehensive information of conversion rates* is essential for processes where the input flow transforms into a different type of output flow – for instance, when converting CPW into solid and liquor components. The requirement for waste treatment in various processes incurs an energy cost. Therefore, it is essential to collect *comprehensive data on the energy consumption per process and flow unit.* Furthermore, concerning molasses production, it is of utmost importance to understand *how various specifications, such as viscosity, impact the energy cost, primarily attributable to subsequent enzymatic treatment.*

Supply chain and processes models

Given that the value chain of the Greek pilot is internal, in this case the modelling needs to refer only to the relevant production processes as interconnected DTs (indicated as *DT process model*), for the monitoring and management of the different aspects of the production and be able to optimise the process and calculate production-related KPIs.

The DT process models are based on the corresponding process models presented in Figure 7 and will focus on production performance, the efficiency the waste management, the yield of new products obtained by waste, and the water recycled/saved.

3.1.3 Spanish pilot

Rare-Earth Elements (REEs) are becoming increasingly important in the transition to a green economy due to their essential role in several technologies and applications such as permanent magnets, lamp phosphors, catalysts, and rechargeable batteries. REEs are produced mainly in China, which in 2022 accounted for over 70% of the global production[2]. In the case of rare-earth permanent magnets (PMs) this results in the fact that 98% are imported from China[3]. The fact that exportation quotas are imposed by the Chinese government, raises concerns about REEs availability at the European level. Despite vast research efforts on REEs recycling - mostly at laboratory scale -, up to 2018, less than 1% of the REEs were recycled, mainly due to inefficient collection, technological problems, and a lack of industries supporting the recycling process[4]. Therefore, a drastic improvement in the recycling of PMs from WEEE is an absolute necessity that can only be achieved by developing efficient, fully integrated recycling routes.

One of the goals of the Spanish pilot is to identify best practices and procedures to expand the reuse and recycling of WEEE. Through the creation of a virtuous circle between key partners active in the sector, the aim is to recycle and recover magnetic materials, process them to decontaminate them from hazardous substances and create Secondary Raw Materials (SRM), to be used in the production of new permanent magnets. This is expected to reduce WEEE disposed in landfills and produce secondary raw magnetic materials, thus diminishing the dependence from China and to improve the resilience and economic return of European manufacturers.

Specifically, the supply chain involves 3 partners: FERIMET, IMDEA, and IMA.

FERIMET is the Celsa Group Company dedicated to the recovery and treatment of ferrous and non-ferrous materials. Nowadays FERIMET receives 24,8 Tn/year of WEEE containing different kind

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[2] https://www.statista.com/statistics/270277/mining-of-rare-earths-by-country/
[3] https://eit.europa.eu/sites/default/files/2021_09-24_ree_cluster_report2.pdf
[4] https://www.snexplores.org/article/recycling-rare-earth-elements-hard-reuse-greener-technology

of motors and magnets. Each WEEE product contains from 0.5 to 300 g Permanent Magnets (PMs) approximately (either bonded NdFeB or Sr-Ferrite, or sintered Sr-Ferrite) depending on the type of electrical motor or magnetic component contained.

IMDEA is an interdisciplinary research centre located in Madrid (Spain) and dedicated to the exploration of nanoscience and the development of applications of nanotechnology in connection with innovative industries. The Group of Permanent Magnets and Applications is part of the Nanotechnology for Critical Raw Materials and Sustainability Programme at IMDEA Nanoscience. This Programme focuses on the application of research and innovation to overcome the fragile economic, political, and social challenges faced by Europe in relation to the procurement of critical raw materials that are essential for a sustainable technological development.

IMA is a Spanish company leader in the magnetic sector, with more than 30 years of experience and a globally recognized magnet supplier, with customers from more than 60 countries. IMA core business is the development of technologies to improve the process of transformation, rectification, magnetization and customization of magnets.

Pilot scope: WEEE recovered by Ferimet, are processed and transformed into magnetic pellets by IMDEA, and used by IMA for the production of new magnet upon customers' request. The focus of the pilot is to optimise the energy consumption of the production line, and to minimize the import of Raw Materials, thus creating an integrated circular economy framework towards maximizing the use of SRM.

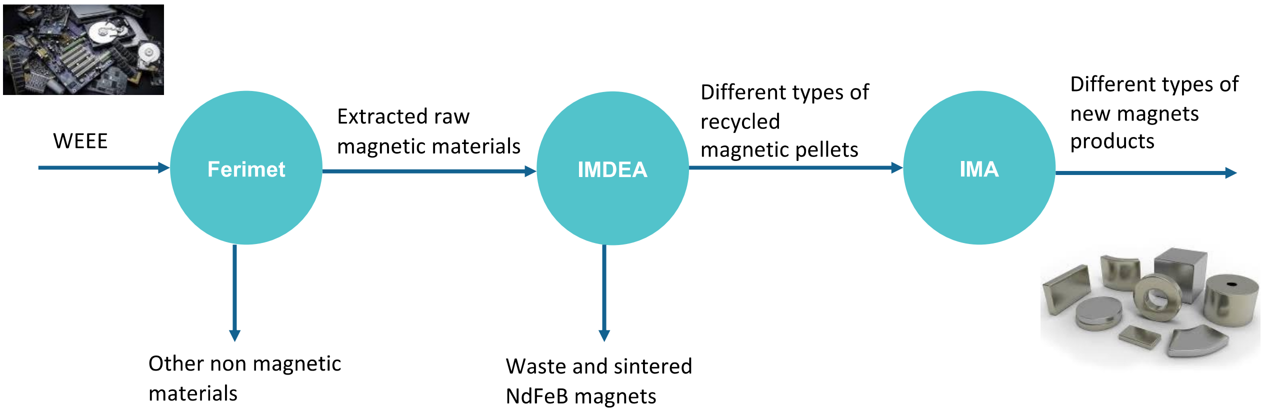

Figure 8: Spanish pilot value chain

Figure 8 provides a very high-level description of the Spanish pilot value chain and the main outcomes. The internal processes are fully described in Figure 9.

3.1.3.1 Needs

Process modelling and simulation

The Spanish pilot ecosystem is comprised by a linear three-actor value chain (Figure 9).

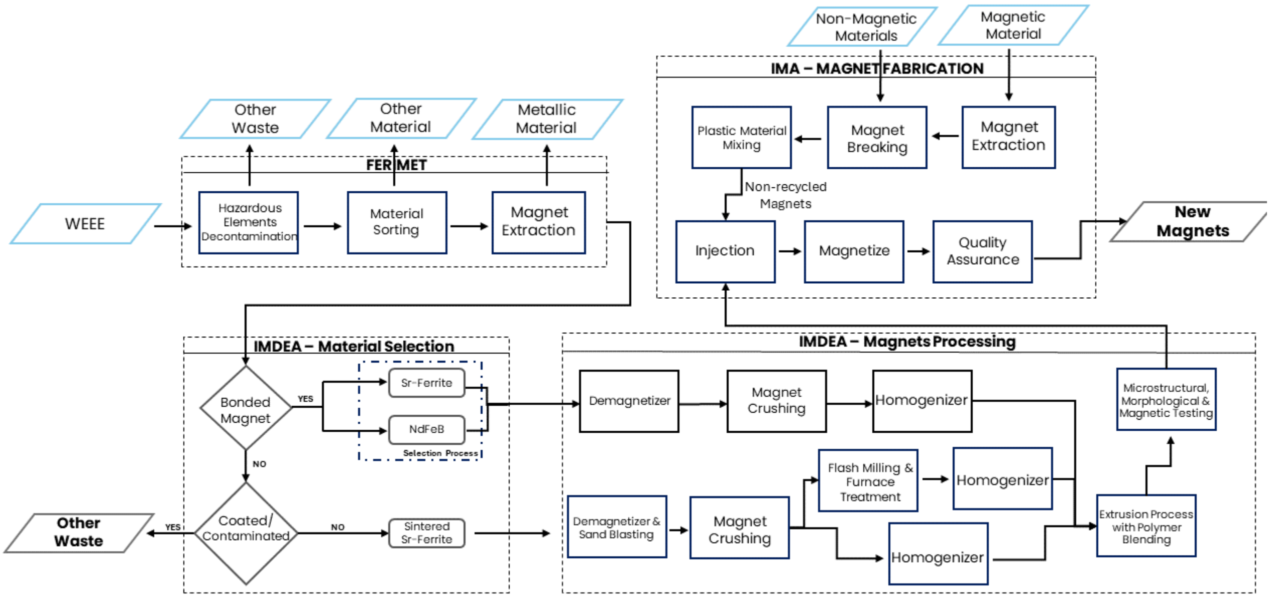

Figure 9: Spanish pilot: value chain and process model

<u>Scope</u>: The PMS is focused on developing a process model of the value chain regarding (a) management of Waste from Electrical and Electronic Equipment (WEEE) and magnet extraction (FERIMET), (b) magnet sorting and material selection (IMDEA), (c) magnet processing and magnetic pellets construction (IMDEA), and (d) new magnets manufacturing and quality assurance (IMA).

<u>Impact</u>: The PSM tool models the entire value chain by offering a comprehensive and detailed representation of processes, accommodating various educational levels and specializations. It effectively maps out inputs, outputs, physical connections, interactions, and the flow of materials, data, and energy within the value chain. Acting as a crucial interpreter, PSM integrates analytics and optimization services. It incorporates analytics-driven insights to refine model accuracy, aiding the optimization tool in delivering efficient and robust solutions. As an essential component of the Plooto suite, it plays a pivotal role in decision-making processes. PSM enables tailored monitoring, investigation, identification, and evaluation of diverse scenarios, including root-cause analysis, what-if analysis, and comparative assessments. Its design as a reusable, expandable, adaptable, updatable, replicable, and API-available tool reduces the overall effort and enhances its integration with associated services, underscoring its versatility and effectiveness in varied applications.

<u>Data Requirements</u>: An analytical description is vital to outline the various stages involved in production processes. This should include a comprehensive breakdown of each process stage,

describing their specific tasks and the applicable machinery along with the corresponding quantitative features (setup times, processing duration, maximum equipment capacities, etc.). Additionally, it involves examining the potential use of primary inputs (recovered magnets / non-recycled magnets), secondary inputs (energy consumption, non-magnetic, plastic materials), and based on these the processes followed for the final magnet production.

Analytics

The magnet recycling pipeline contains different points where analytics can be applied giving and thus allowing to implement different scopes in the pilot. The main nodes where analytics techniques can be implemented are in the first to pilot partners. The pilot use case first relies in the obtention of the maximum quantity of magnets for each type of the defined magnet types, and then it has different nodes in the production of pellets where the change of manufacturing parameters can affect the properties of the magnetic powder.

In the magnet type prediction use case, data-driven methodologies are going to be used with the data generated from the magnets' extraction at Ferimet, where the WEEE source of the magnet will be recorded in their DPP. This application will use recorded data to generate a classification from each source of WEEE used to extract magnets and predict the type of magnet contained before it is dismantled. This will be performed by multiclass classification algorithms, that for each WEEE, will generate a probability to recover each type of magnet.

The second use case for data-driven applications in the supply-chain, is the prediction of magnetic properties of the magnetic powder to produce the pellets. This prediction can be performed based in the initial magnets to be recycled and the different manufacturing parameters. For that, IMDEA supplies manufacturing data not related with the DPP that will be used to train data driven models to predict final magnetic properties of the magnetic powder and develop an AI assistant for the selection of manufacturing parameters.

For the prediction of the magnetic properties, it is important to acknowledge that AI based methodologies may face limitations due to possible bias in the data, the presence of stochastic factors or hidden variables that are not currently measured. For this reason, the presence of a research centre recycling the magnets assure the presence of the required human expertise to mitigate any issue identified during the development of data-driven algorithms and the analysis of their results.

Optimization

Scope: The focal point of optimization in this pilot case is to *reduce the energy consumption of the production line while minimising the use of raw materials*. In essence, the optimization service operates upon the flow of WEEE within the value chain and decides for the optimal operating strategy of different process units. The whole proposal is built around the circular economy paradigm to reduce the amount of waste of electrical and electronic equipment that ends up in landfills. The result will also be to reduce by 30% the import of raw materials from abroad and at the same time to enhance the economic performance of the enterprises involved in this project, and at the state level to reduce imports, resulting in the development of the state economy.

Impact: The optimization model is designed to significantly *improve the overall efficiency of the flow involving three key magnetic materials*: *Bonded Sr-Ferrite, NdFeb, and Sintered Sr-Ferrite, within the waste recycling process. The primary goal is to produce high-quality recycled magnetic pellets.* To achieve this, the waste flow undergoes various processes, including the separation of recyclable, non-recyclable, and hazardous materials. This facilitates the extraction of the targeted magnetic materials from the waste stream. Additionally, the optimization model incorporates the strategic injection of supplementary materials, such as polymeric and plastic components. This is done in order to meet specifications dictated by the corresponding demand. By tailoring the composition of the recycled magnetic pellets, the approach ensures the production of Specialized Magnetic Materials (SRMs) possessing the exact properties required for the final products. This method aligns the production process with the dynamic demands of the market, guaranteeing the fulfilment of product specifications and optimizing the overall recycling flow.

Data Requirements: To evaluate the effectiveness of each category, comprehensive data on the *quantity and types of magnets present in WEEE* is essential. Initially, knowing the *specific type of WEEE requiring minimal treatment to extract magnetic materials* with the highest usable content is crucial. Subsequently and within the IMDEA processes the aim is to leverage innovative and more efficient methods for processing magnetic materials. Thus, it is necessary to gather *information on the energy consumption associated with each device and process per product unit*. Additionally, *details on device settings, processing conditions, and processing costs for the three distinct materials* (Bonded Sr-Ferrite, NdFeb, and Sintered Sr-Ferrite) are essential for a comprehensive analysis. Furthermore, given the blending procedures involved in both IMDEA and IMA, where magnetic materials are combined with different substances like polymers, obtaining *data on quantities and ratios* is vital. This information is crucial for ensuring the production of the correct product that meets quality control standards, ultimately contributing to the manufacture of high-quality permanent magnets.

Supply chain and processes models

The *DT supply chain model*, involves all pilot partners as depicted in Figure 10.

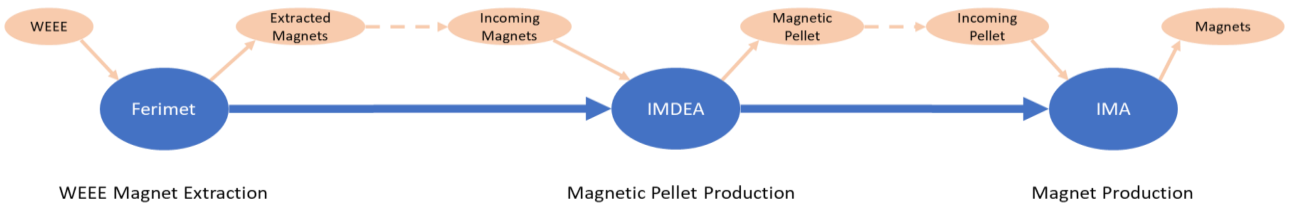

Figure 10: Spanish Pilot DT supply chain model

Table 2: Spanish pilot key processes and roles

Partner	Process	Roles
Ferimet	WEEE Magnet Extraction	Starts the recycling supply chain. Receives WEEE to extract the magnets present in different components.
IMDEA	Magnet Pellet production	Transformation of the raw material (extracted magnets) into a secondary product (pellets).
IMA	Magnet production	Transformation of the secondary product (pellets) into the final product (new magnets).

The supply chain will be modelled using corresponding features presented in the Digital Twin modeller described in Section 5.4.2. The configuration of the supply chain concerns the data to be exchanged among the parties (Task 2.1).

The **DT process models** will be based on the processes described in Figure 9, and will concern essentially the activities performed in IMDEA for the extraction of magnets, and the production in IMA, with a focus on sustainable production and to maximise the use of SRM in the production of new magnets.

3.2 Requirements

A software requirement is a capability needed by the user to solve a problem or to achieve an objective. In other words, requirement is a software capability that must be met or possessed by a system (or system component) to satisfy a contract, standard, specification, or other formally imposed documentation.

Therefore, requirements serve as a formalized expression of the actualities inherent in an IT system, deriving directly from the expectations and requirements of invested stakeholders—those entities poised to be the primary beneficiaries or users of the system.

Requirements are categorized by different levels and types that build a hierarchy represented in Figure 11.

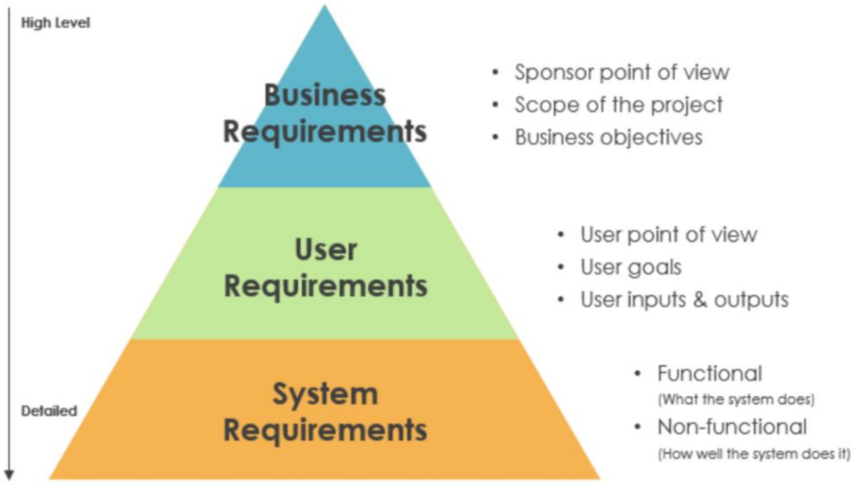

Figure 11: Requirements hierarchy[5]

The first step is to identify the **Business Requirements**, statements that represent the *customer point of view*, the scope and the main objectives and provide a high-level description of the system to be implemented. This initial vision is further detailed in **User Requirements**, addressing the *user point of view*. At this level the focus is more on operational aspects describing how the user wants to use the system, what are the user's goals and the data that needs to be managed.

User requirements, which are usually expressed in natural language, need to be transformed into **system requirements** that are classified into two categories: **Functional requirements**, which elucidate the expected behaviour and functionalities the system must offer to fulfil user needs and desires, and **Non-functional requirements**, which transcend the functional aspect of the software. Non-functional requirements articulate specific criteria that can be employed to assess the system's performance, security, and availability, among other factors.

In the scope of this deliverable, the "business view" is that of the central platform that needs to satisfy different "customers" with different needs.

Therefore, this deliverable does not detail the business functionalities requested by a specific user, but rather it aims to look at more general user needs that should be fulfilled in CRIS (Plooto platform).

The description of the pilot cases, which can be regarded as an expression of user requirements, allow to derive the **Functional requirements** that will be implemented as functionalities that the platform should expose to allow the execution of pilot scenarios. While the existing constraints and required performance, as well as the specific horizontal functionalities and their communication protocols provided by technical partners, allow to specify **Non-Functional requirements**.

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[5] https://www.visual-paradigm.com/project-management/different-types-of-requirements

The Functional and Non-Functional requirements have been identified through the analysis of the pilots' needs, and the proposed use of the tools and technologies provided by the project. They are reported in Table 3 and Table 4 respectively.

Table 3: Functional Requirements

Id	Requirement	Priority	Pilots
FR-01	The user should be able to establish and manage collaborations with other partners within the supply chain.	High	Italian Spanish
FR-02	Data exchanged among partners should be maintained in a secure way. Users should have access only to the information and features that are relevant for their case.	High	Italian Spanish
FR-03	The user should be able to use/combine tools/ technologies locally available.	High	All
FR-04	The user should be able to define processes eventually combining services and tools from different providers.	High	All
FR-05	The user should be able to monitor internal processes having real time information	High	All
FR-06	The user should able to use and integrate different types of assets.	High	All
FR-07	The user should be able to simulate the production process based on user defined parameters.	High	All
FR-08	The user should be able to simulate parts of the production process	Medium	All
FR-09	The user should be able to execute process optimization scenarios based on user defined parameters.	High	All
FR-10	The user should be able to optimize the supply chain	High	Italian Spanish
FR-11	The user should be able to use analytics services to gain insight about the processes and possible improvements	High	Italian Spanish
FR-12	The user should be able to assess the production process and detect environmental hotspots and/or potential areas for improvement through LCA	High	Greek
FR-13	It should be possible to compose the Digital Product Passport aggregating data from different processes	High	All
FR-14	The Digital Product Passport should be maintained in a secure way and it should be publicly available.	High	All
FR-15	The agreements among the parties in the supply chain should be managed within the platform	High	All

Table 4: Non-Functional requirements

ID	Requirement	Priority
NF-01	The platform should be able to connect with external systems (mobile apps, legacy systems, open data sources etc.)	Low
NF-02	The platform should have UI customization features and offer customization display capabilities.	High
NF-03	The platform must be able to generate and send notifications and alerts	High
NF-04	The platform must grant user-based and role-based access through secure protocols	High
NF-05	The platform should be compliant with Data Spaces	High
NF-06	The platform should be able to connect with external party's trough IDS-Connectors.	Medium
NF-07	The agreements (smart contracts) among the parties in a supply chain should be securely stored.	High
NF-08	It must be impossible to tamper the agreements (smart contracts) among the parties in a supply chain.	High
NF-09	The platform should provide access to the different modelling tools	High

4 Information modelling framework

This section reports the work done in Task 1.3 (led by UiO) to formalize the Information Modelling Framework (IMF) language to be applied to the different pilot cases of Plooto. IMF is an intermediate language meant to be used by Engineers to model systems and, by extent, to easily create formal ontologies for those systems without need-to-know ontology modelling, which has been proven very complex and difficult to be used by regular production engineers.

In Plooto, IMF is used for capturing the semantics and specification of the DPP by creating the semantic model of Plooto and the ontology for the pilots. This ontology, when populated with the pilot data, will create the knowledge graph which then can be used by the rest of the project partners for various reasons such as semantic interoperability and formalization of the DPP.

IMF was selected over other tools as it is an engineering friendly language allowing engineers to model using their own language. The created models can be translated into a formal ontology.

The scope of the IMF models is to capture the basic entities of the pilots and their connections. Once the IMF models reach a certain level of maturity, they are going to be transformed to a formal ontology that can be used from the different partners. Once the ontology is produced it will be populated with the Pilot data and produce the knowledge graph. Since the IMF language is under development and hides high complexity, the IMF modelling efforts will be focused around the Spanish pilot.

To improve the readability IMF basic principles are presented in Appendix A, while the following section presents preliminary models for the Spanish pilot using IMF language.

4.1 Spanish pilot modelling

The Spanish pilot consists of 3 nodes (aka partners) illustrated in the figure below. Each of the node has a different role and different products. Using the IMF language, a first draft version of the "Product" and "Function" aspects have been created. Those are a preliminary form of the final models, as the models are continuously updated using information collected from the different Plooto partners.

Figure 12: Spanish pilot nodes and products

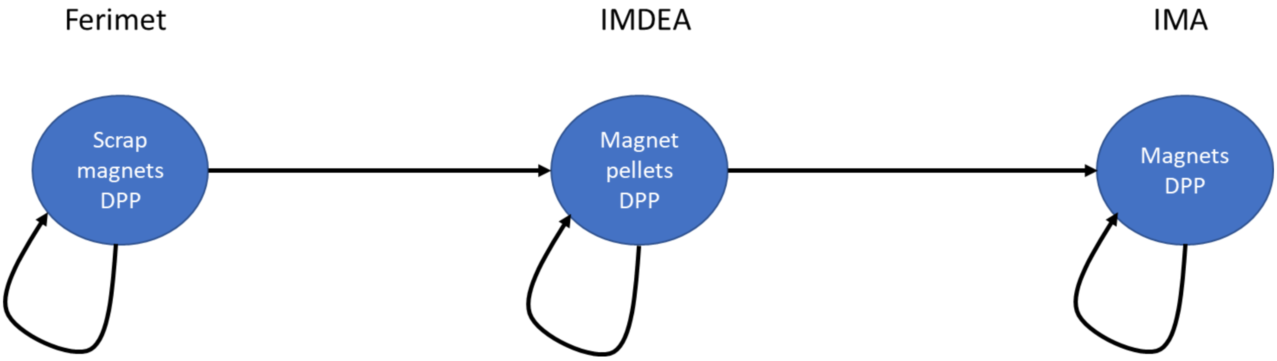

Figure 13: Data aggregation for the DPP

In engineering practice, it is natural to describe systems from different points of view, typically from the views of physical artefacts, activity, and location. IMF is a language designed for describing systems from such different points of view, which we refer to as “aspects”. The notion of aspects is essentially the context of modelling that needs to be clarified before modelling, e.g., whether it is about the physical artefact or about the activity, what the purpose of modelling is, and who the users are. Note that the aim of IMF language is to describe systems, not to define systems.

- The Function Aspect (yellow) is to specify the intended activity, e.g., the information about activity, performance, and function about a pump.
- The Product Aspect (cyan) is to specify the intended solution of a set of physical artefacts to perform the activity, e.g., the information about the physical artefacts of the pump.

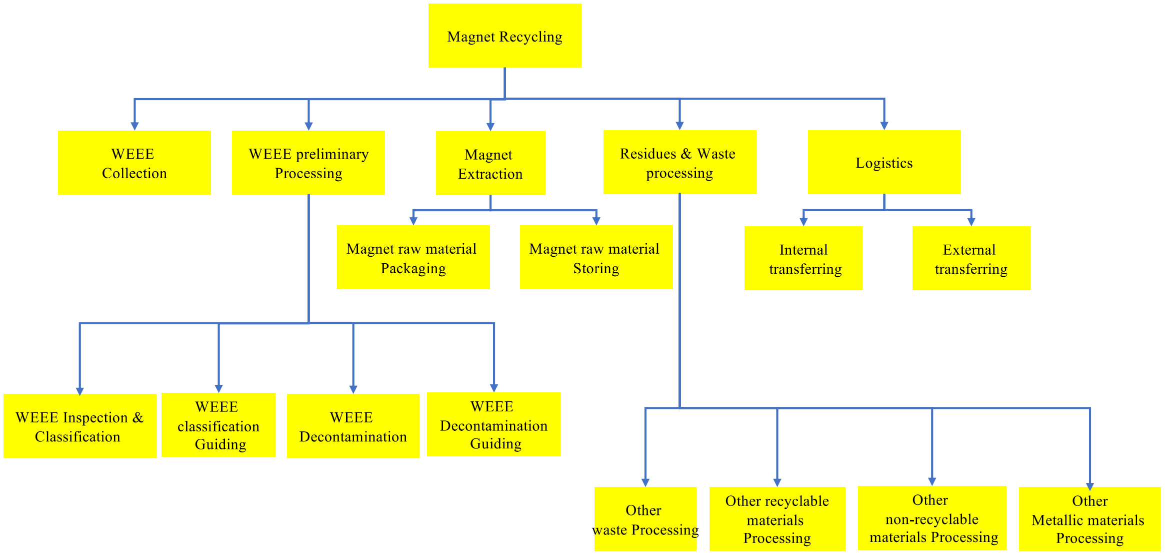

Figure 14: Functional aspects, Ferimet

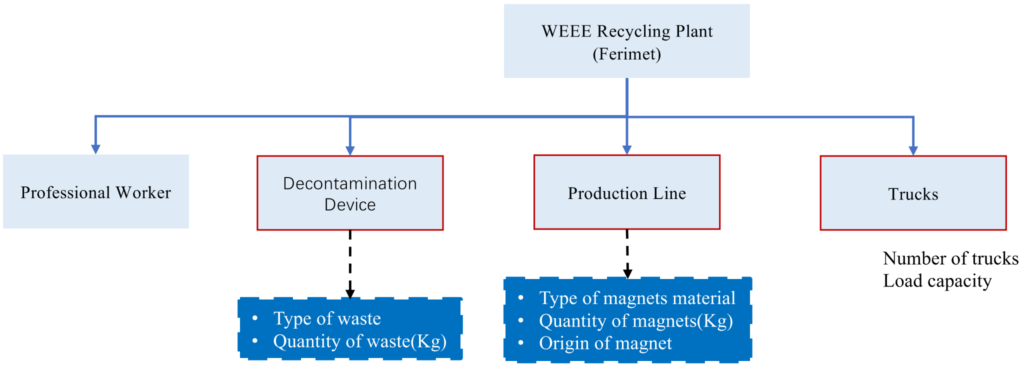

Figure 15: Production aspects, Ferimet

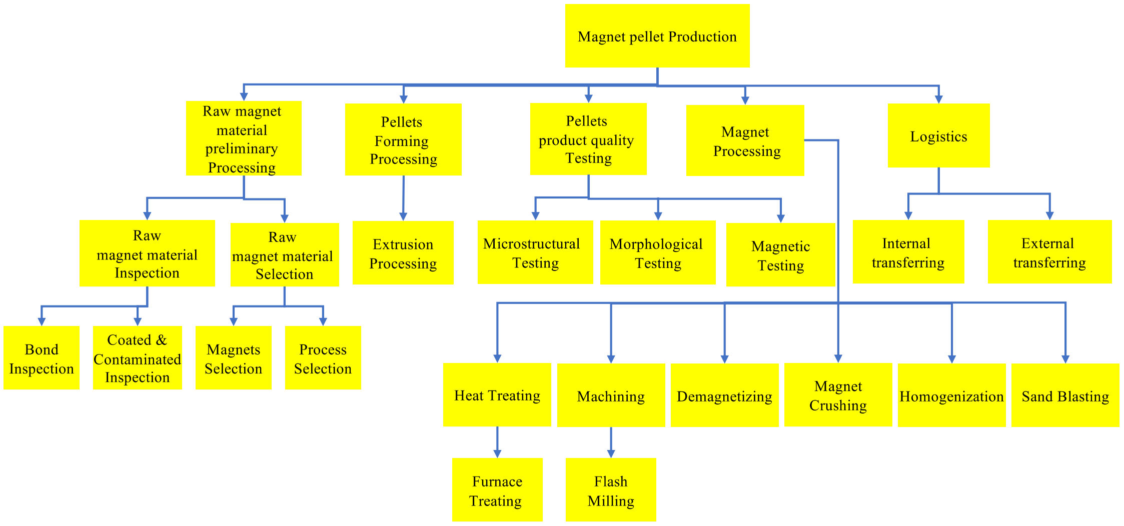

Figure 16: Functional aspects, IMDEA

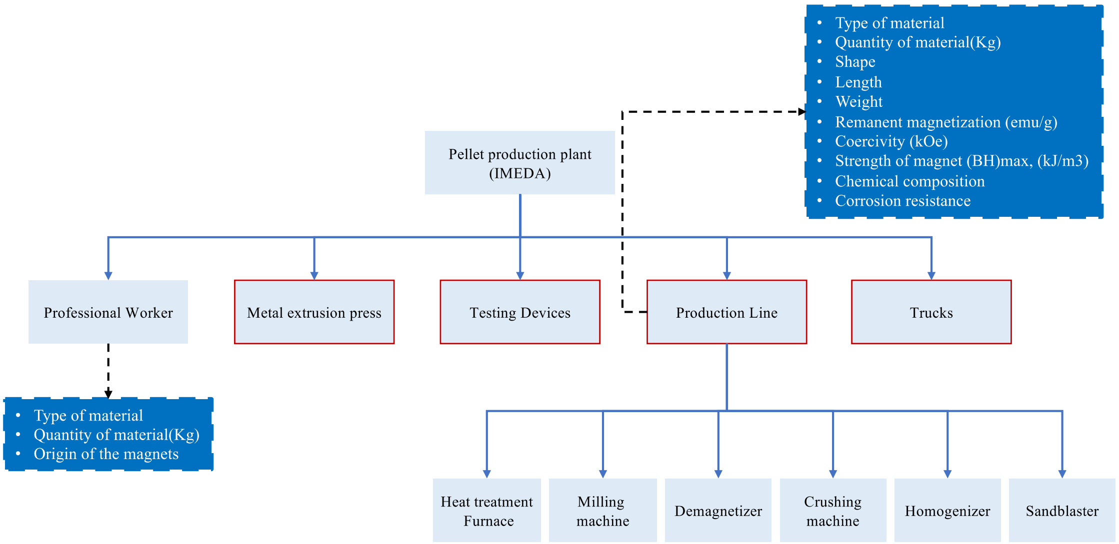

Figure 17: Production aspects, IMDEA

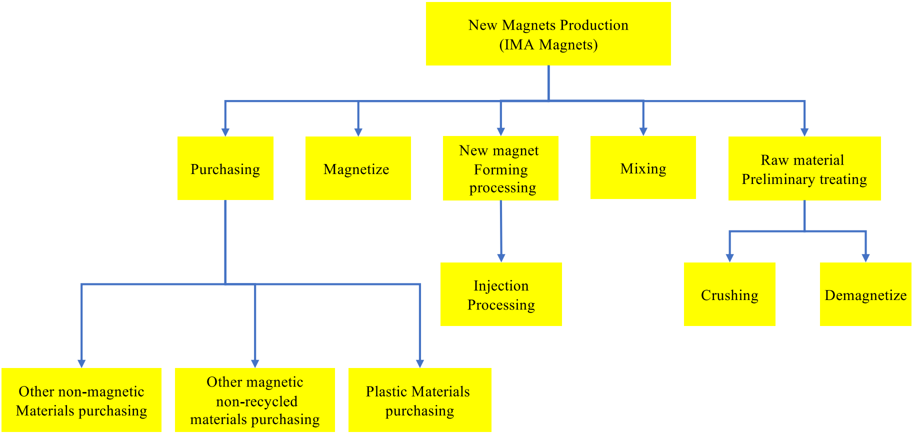

Figure 18: Functional aspects, IMA

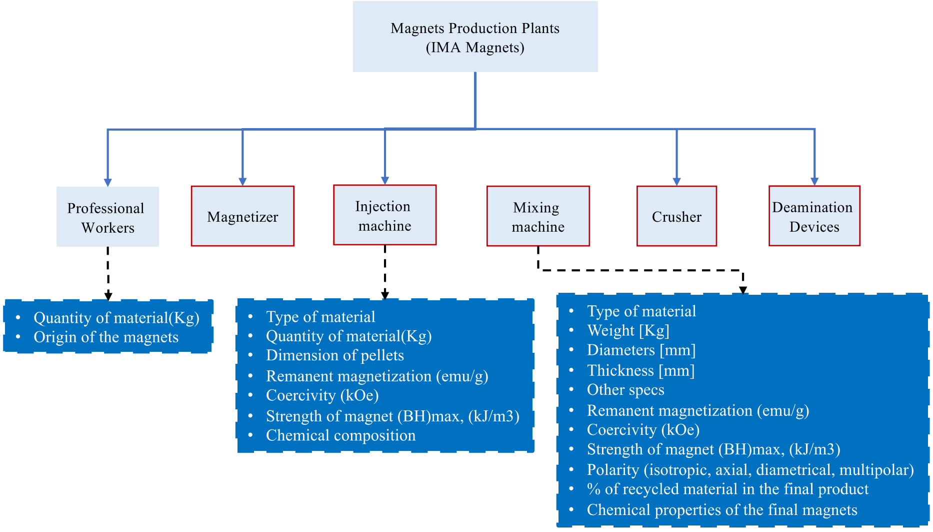

Figure 19: Production aspects, IMA

5 Architecture

CRIS aims to provide the environment where pilot users can model their system, monitor and operate the needed features (simulation, optimisation, analytics), trace resources and materials involved in the production, aggregate relevant product information in the Product Digital Passport (DPP), and finally assess and measure the efficiency and the different KPIs. The DPP is an artefact that follows the production throughout the supply /value chain. The needed information at each of the production steps is aggregated in a digital structure that will be secured and made available to the final customer. CRIS is an integrated system, in the sense that components, tools, and information stored in different subsystems, and brought together into a single functioning unit.

The initial requirements have been analysed to derive the first draft of a layered architecture layout that is presented in Figure 20.

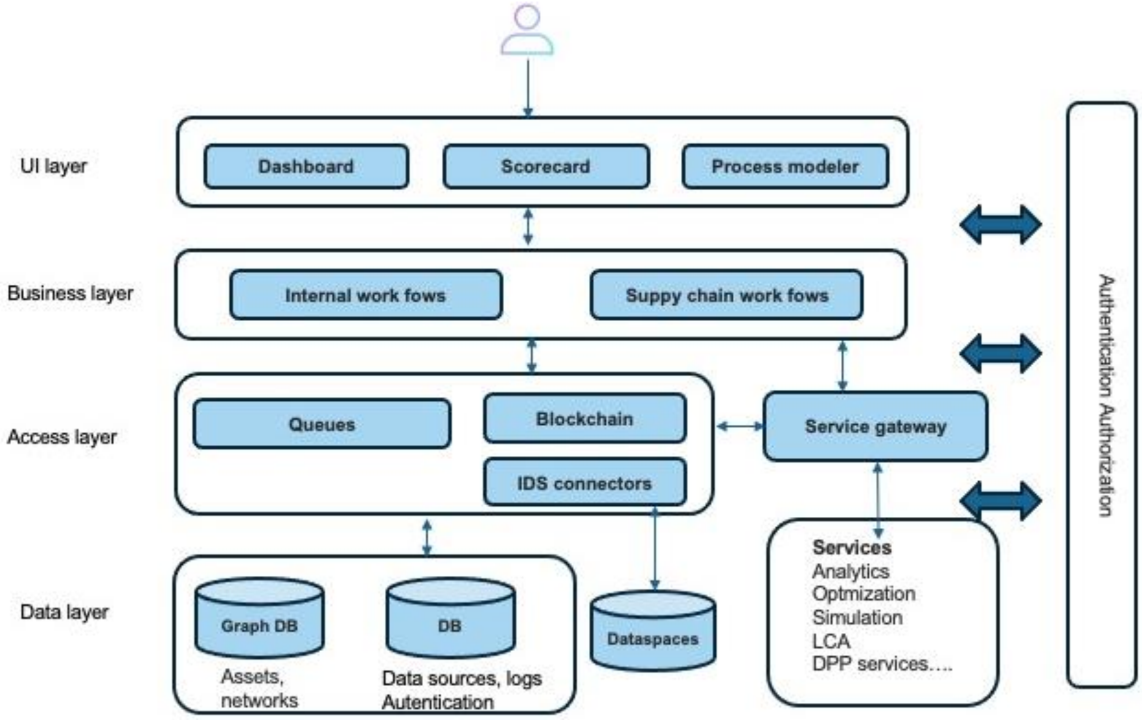

Figure 20: CRIS architecture, layered view

5.1 Overview

CRIS architecture comprises four major layers: User Interface (UI), Business layer, Access layer, Data layer. These layers are an aggregation of components / modules / tools, which provide functionalities that can be logically related. The architecture includes also horizontal features to manage the access to the platform (i.e., authentication/authorization). The service gateway is a logical component that allows the smooth integration of services provided either by the technical partners or – in the future – by third party providers. Finally, the architecture is designed to be compliant with Data Spaces – as an additional collaboration/data exchange channel – and blockchain for the secure maintenance and management of relevant data. Each layer and its modules are described in the following section.

CRIS is built upon MIRA, a Digital Twin enabler platform developed by MAG in previous EU projects (i.e., FACTLOG, TREEADS). This platform is not a commercial solution, but rather the first set of building blocks that are further enriched with additional components that develop the features needed by Plooto pilots and integrates the added value services to be developed in WP2.

5.1.1 Authentication /Authorization

This layer aggregates the features that implement Identity Access Management (IAM) in Plooto. These two concepts are crucial to safeguard digital systems and sensitive data, thus ensuring the integrity, confidentiality, and availability of resources within the Plooto ecosystem.

Authentication is the process of verifying the identity and to establish trust in the identity of the entity attempting to access the system. Authentication methods can vary widely, encompassing something a user knows (such as passwords or PINs), something they have (like smart cards or security tokens), or something they are (biometric data such as fingerprints or facial recognition).

Authorization, on the other hand, determines what actions or resources that an authenticated user is allowed to access or manipulate, ensuring that users are only able to perform actions or access information that aligns with their designated level of authority within the system. Authentication is responsible for granting or denying specific permissions based on the authenticated user's roles, privileges, or attributes.

Together, authentication and authorization form a robust security framework that helps mitigate the risk of unauthorized access or misuse of sensitive information, and helps maintain the confidentiality, integrity, and availability of digital assets.

Authorization can be implemented following different strategies, depending on the specific requirements, complexity, and security goals of a given system or organization. The most used strategies to control access to digital resources are: *User-based authorization,* which grants permissions to individual users, and *Role-based authorization*, which grants permissions to predefined roles, for instance job functions, or position in a team. The first offers a higher granularity, but it also comes with a higher administrative burden, the second simplifies management but might lack precision.

In CRIS, a combination of these two strategies will be used, thus ensuring a balance between flexibility and simplicity in access control, while creating a comprehensive and effective access control framework and enhancing overall security in diverse digital environments.

5.1.2 User Interface layer

The user interface layer comprises visual tools that allow the user to have access to resources and to operate on assets and procedures.

From a functional perspective, the UI serves three main purposes: i) it provides the core features to model the pilot ecosystem in terms of interconnected Digital Twins, and to specify the assets to be monitored and the KPIs to be measured; ii) it provides the operational environment where pilot operation are executed; iii) it provides access to supportive tools developed within Plooto (e.g., Process Modelling Tool (PMT)) where to simulate alternative configurations, or the Balanced Scorecard (BSC) to assess the impact of the process according to different parameters.

5.1.3 Business layer

The Business layer is where users can define and monitor their pilot in terms processes, and eventually un terms of supply chain.

MIRA, which is at the foundation of CRIS, provides the modelling features to design processes and the supply chain. A process- designed with the PMT, can be modelled as a network of interconnected DTs, each having its characterizing properties, telemetries that will provide data supporting the monitoring phase, and associated services (e.g., simulation, optimization, analytics, etc.).

The *Digital Twin consortium* defines “A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity”[6]

This concept establishes a biunivocal relationship between the digital twin and its physical counterpart. Besides providing real time information on the status of the DT, this synchronized bi-univocal relationship allows to manipulate the structure and behaviour of the virtual object as if it is the real object, thus to use appropriate services to simulate and predict the behaviours of the physical world.

The state of the physical system is reflected in the digital system and vice versa.

Although Digital Twins were initially associated to sensors and machineries, their applicability can be expanded to include people, organizational entities, services, and processes.

This more general concept, that can be referred as Digital Asset (DA), allows to use the DT approach to potentially everything and it is the concept used in CRIS. Therefore, the supply chain can be designed as interconnected DTs, defining the connection points and the data to be exchanged. However, in this case additional precautions concerning data ownership and visibility need to be put in place.

Once the processes - and eventually the supply chain - have been modelled, the user can customise the home page in order to highlight the aspects that need to be monitored. The business layer is in fact connected on one hand with the Access Layer, which provides the

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[6] Digital Twin Consortium (2023). Definition of a Digital Twin.

mechanism to access data, on the other hand to the Service gateway, which enables the user to invoke the needed services.

5.1.4 Access Layer

The Access layer contains all the components to access the actual data. These include:

Queues (e.g., RabbitMQ) are used to collect requests or data from the outside, enqueue them before they are consumed, associated to telemetries and stored in the appropriate data bases.

Blockchain is a decentralized and distributed ledger technology that enables secure and transparent recording of transactions across a network. Due to its main characteristics, decentralization, transparency, and immutability, blockchain is the technology used to store data that requires more stringent security. The most significant characteristics of Blockchain are: *Data immutability* – which ensures that no data is corrupted. *Decentralization* – meaning that no authority or government, nor a group of persons, or a single individual, controls this technology. *Transparency or provenance*: which ensures that every transaction can be traced from the start to the finish. Blockchain is based in the peer-to-peer protocol and each transacting entity is represented by a peer in the network.

IDS connectors from International Data Spaces Association (IDSA) are increasingly proposed in multiple domains around Europe. In the Plooto project, this component will have a critical role as it provides secure exchange of data, enables the creation and enforcement of data access policies and agreements, supports traceability, and integrates with digital twin infrastructure to support business cooperation.

IDS Connectors facilitate secure data access by only allowing data access on the basis of bilateral agreements. Moreover, the enforcement of these agreements is established by additional internal libraries that allow unambiguous access rights. These architectural elements enable a limit to the movement of data in the data space, which guarantees data sovereignty and compliance with commonly accepted industry standards.

In the context of a digitally-enabled circular economy, traceability and digital passports are of the utmost importance. The integration of multiple data sources through the use of connectors ensures that critical information is exchanged in a timely and reliable manner in a business ecosystem. IDSA-compliant connectors, coupled with digital twin infrastructure, can provide the basis for fair data access, promoting cooperation among businesses, and enabling the development of innovative solutions in a competitive yet collaborative environment.

To support the above functionality, IDS connectors are designed as complex, decentralized components, that in the context of Plooto, will be demonstrated in the different services and data storages. We plan to base our efforts on both existing open-source and in-progress software solutions, adapting them to better fit the pilot needs.

5.1.5 Data layer

Data bases the data layer contains all the databases, CRIS make use of different types of data bases: graph-based data base, for instance Neo4J, is used to store information about the DT models and it maintains the graphical representation. While other types of data bases (e.g., SQL, NoSQL, or document-based) should be used will be used to store other types of information and data, for instance transaction logs, authentication/authorization, or data characteristics of the pilot's assets and telemetries.

Dataspaces Data Spaces have rapidly become a critical component of the data layer in businesses around Europe, also supported by the European Commission's vision of a unified market for data. A data space, as a virtual data sharing environment, enables the direct exchange of data between businesses. Additionally, data spaces facilitate the exchange of information across the value chain, engaging stakeholders such as research institutes, industries, and consumer associations.

The functionalities of data spaces enhance and expand business operations. Data spaces enable direct, real-time, dynamic, and secure data exchanges, between businesses. The digital contracts formed in these spaces guarantee the security and trustworthiness of exchanges, and data sovereignty. Furthermore, data spaces encourage the cooperation of a community, where different actors can collaborate on specific topics around a given domain.

We also plan to use dataspaces to encourage the data exchange in an environment characterized by limited trust and co-opetition (a blend of competition and collaboration). Specifically for the transition to the circular economy, data spaces will support traceability and the secure creation and management of digital product passports.

5.2 Architecture Components

Figure 21 provides an overview of the main components of CRIS architecture, which are briefly described in the following paragraphs.

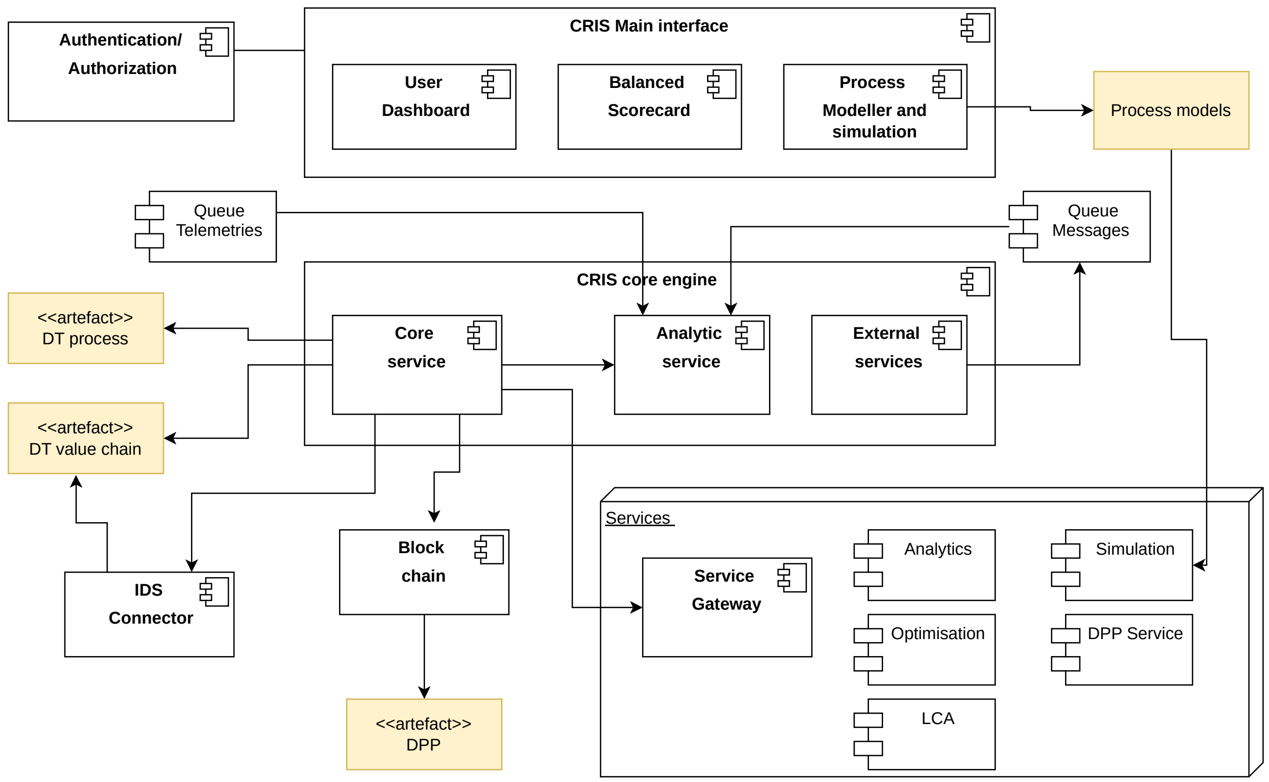

Figure 21: CRIS architecture - Component diagram

5.2.1 Authentication /Authorization

CRIS IAM authentication IAM will be based on Keycloak[7], an open-source Identity and Access Management (IAM) solution designed to secure applications and services. The user credentials are stored in a PostgreSQL database. The Keycloak features more relevant for Plooto are:

Single Sign-On (SSO): Enables users to log in once and gain access to multiple applications without needing to log in again, enhancing user convenience and security.

Authentication and Authorization: Offers flexible authentication mechanisms and supports fine-grained authorization policies, ensuring that users have the right level of access to resources

Token-Based Security: Utilizes tokens (such as JSON Web Tokens or JWTs) for secure communication and access control between applications and services.

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[7] https://www.keycloak.org

5.2.2 CRIS Main Interface

This logical block aggregates the modalities to interact with the system: the dashboard, the Process Modeller and Simulation tool and the Balanced Scorecard tool.

Dashboard.

Represent the main user interface to the system. It is one of the native features provided by MIRA allowing the modelling of the ecosystem in terms of Digital Twins and the operational monitoring and management of the user ecosystem. Users need to define the system they want to manage in terms of digital assets, networks and relationships and define eventual process to be orchestrated. The dashboard can be customised to better fit the monitoring or operational needs of the user (for instance to connect to specific services, or to monitor relevant KPIs).

Sustainability Balanced Scorecard tool

The main webpage embeds the SBSC tool, which is based on Plooto Sustainability and Governance Framework and allows monitoring of KPIs supporting an informed decision-making. Refer to Section 5.4.3 for a detailed description of the Tool.

Process modeller and simulation tool

The main webpage embeds the PMS tool, which allow users to describe their internal processes and run simulations and what-if scenarios. Refer to Section 5.4.1 for a detailed description of the Tool.

5.2.3 CRIS main engine

Core service

Is the core component of the platform that manages all the requests coming from the users and propagating them to other services and return a response to the dashboard. The Core service manages the user business logic of the application concerning Networks, Assets, their relationships, and the processes the assets are involved into.

Analytics service

This service is responsible for batch-consuming messages from the telemetry-logs queue and storing the data in a database. This feature is propaedeutic for generating analytics. Users can post data regarding a given Data source to that queue. It can be used to send data streams related to a given telemetry or group of telemetries.

External services

This component consumes messages sent by the Core service to Queue messages. It is used to send alerts and notifications via email to involved stakeholders.

Queues

CRIS main engine uses two distinct queues: **Queue messages** consumed by the External service, and the **Queue telemetries** consumed by the Analytics service.

5.3 Connectors

5.3.1 IDS-Connector

The IDSA-compliant connector will play a pivotal role in enabling secure and trusted exchange in Plooto's distributed environment. The connectors aim to provide a standardised interface for the issuance of agreements, thereby ensuring the data sovereignty. It enables interoperability among diverse systems and platforms, allowing seamless data exchange while adhering to predefined rules and policies.

We plan to use the Eclipse Dataspace Components (EDC)[8] as a framework for sovereign, inter-organisational data sharing. In addition to the IDSA protocols, these components implement the IDS Dataspace Protocols (DSP) and relevant protocols associated with GAIA-X[9]. The existing Eclipse software will be extended and adapted to meet the specific needs of the pilots, while maintaining a functionality that is generalizable for actors in a circular economy setting.

The IDS connectors will allow ad-hoc connections between different actors and the negotiation of agreements. Once an agreement has been concluded, the connector allows the secure and limited exchange of data. Multiple components contribute to this functionality (Figure 22).

The connector provides APIs for integration with various systems, enabling customization and extension of its capabilities. As an endpoint for data sharing, the connector will provide secure REST APIs. Additionally, a User Interface will be available for the monitoring of data exchange, as well as the negotiation and management of agreements between different actors.

We expect the connector to be used as a primary tool for data sharing in the value chains in the Plooto ecosystem. Moreover, the connector will be a fundamental building block in settings where data protection and data sovereignty regulations need to be adhered to.

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[8] https://github.com/eclipse-edc

[9] https://gaia-x.eu/

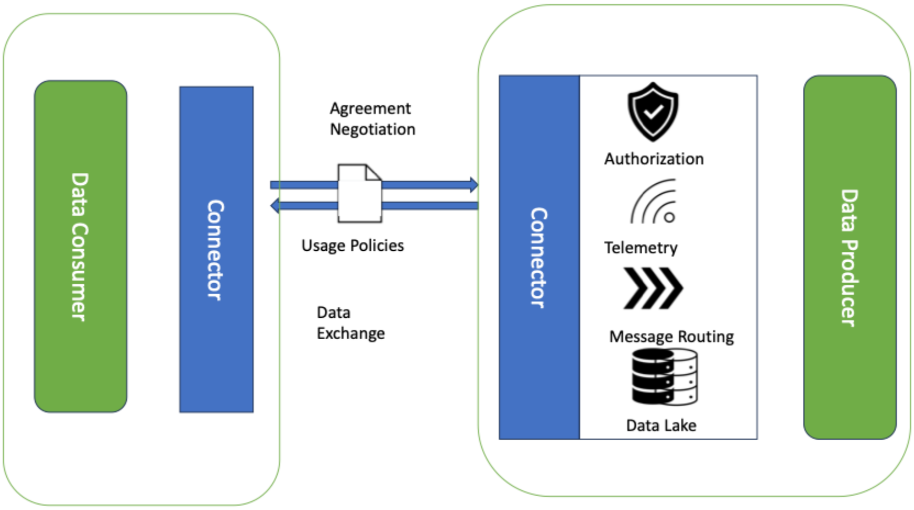

Figure 22: Basic IDS Connector

5.3.2 Blockchain

Blockchain technology will be utilized in the context of Plooto as part of the *access layer* to offer additional security and provide a robust template for sharing DPPs among organisations. It is the technology that best fits the needs to support circular value chains among organisations on a trusted environment.

The use of blockchain technology offers the canvas that organisations can use to craft contracts between them and the underlying sharing mechanism of the DPPs. This functionality will be supported with the use of smart contracts, which are self-executing contracts with the terms of the agreement directly written into code. There will be smart contracts that dictate how the organisations will send and receive messages and the types of messages with variables directly embedded in the contract as well as free text fields. All transactions take place over an immutable and transparent ledger, ensuring that information recorded in the Digital Product Passport is secure and tamper-proof. This helps build trust among stakeholders and consumers, since the entire history of a product's life cycle is traceable among the peers of the network.

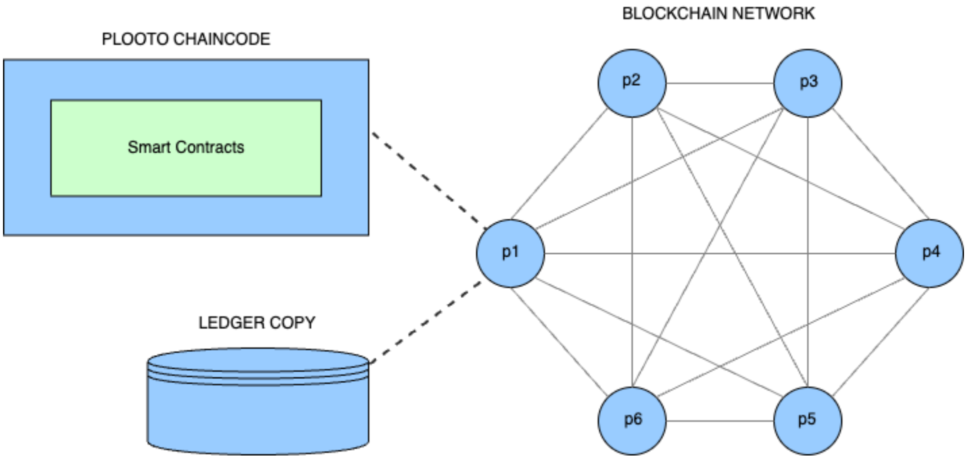

Figure 23: Blockchain chain code

For the needs of Plooto we utilize the Hyperledger Fabric[10] permissioned blockchain platform which is provided by the Linux Foundation. This platform is open-source and it provides a ledger copy for each peer. The chaincode, as depicted in Figure 23 above, is the executable program that hosts the smart contracts. Each smart contract can be seen as a function that will be triggered over REST API calls from the relevant Plooto components offering the end user the ability to craft contracts, add product passports, read and track history of products, and even delete specific products. Note here that the concept of deleting a transaction from the blockchain is not possible but since on many occasions it is a needed feature, Hyperledger Fabric provides this functionality with the use of the World state database. World state, Figure 24 bellow, is what the end users view by default, and it is a snapshot of the last state of the blockchain ledger, over this database a transaction can be deleted but the user is still able to look at the actual immutable ledger to track the history of products. Thus, a dedicated smart contract will be offered, which will crawl the blockchain ledger so that the end users will be able to track all the past transactions and states of a product.

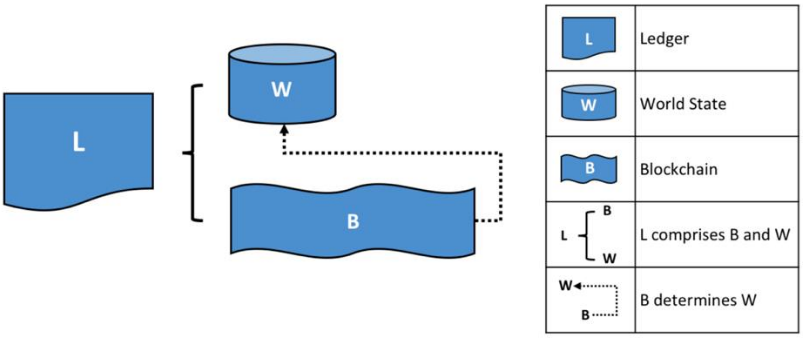

Figure 24: Blockchain world state

For any organisation to be part of the blockchain network, it must abide by the rules that this network has. Meaning, he must comply with the smart contracts that drive this peer-to-peer network. The smart contracts will be designed to map to the transactions and functionality needed and used by the Plooto communication mechanisms and as mentioned above, they will be offered as simple REST API calls, accessible directly over the service gateway. Internally, the blockchain network will also have its own authentication and access control mechanism that will dictate the permissions of the organisations over the network. The smart contracts offered over endpoints integrate Keycloak authentication and the REST API calls can be queried using specified access tokens for each organisation.

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[10] https://www.hyperledger.org/projects/fabric

5.4 Tools

5.4.1 Process Modelling and Simulation tool

The general concept of Process Modelling and Simulation (PMS) tool is to represent the process inputs (raw materials, energy, secondary materials, workload, etc.), the process sub-stages that convert inputs into in-process parts, and process outputs (final products, scrap material, secondary products). Typically, the configuration of a model embodies all the entities implicated in its functioning, with a set of potential conditions in which the physical system may be established succeeding to the occurrence of sequences of events (also described as system's behaviour). In each process stage, appropriate equations are employed to represent the state, properties and variable changes over time during scenarios' simulation.

For the implementation of the pilot process models, four (4) distinct general datasets are required; these datasets will become tailored to the individual characteristics (operational policies, process network structure, resources availability, etc.) and needs (KPIs, Machine Usage, Indexing, etc.) of each pilot. The datasets are specified to address the requirements of the tasks described below.

- The initial task is the construction of the model's architecture. This encompasses the definition of the physical system components, alongside their interconnection and mutual interactions.
- To effectively represent the dynamics of the system over time, quantitative parameters, regarding entities' states, properties and parameters are added to the process model.
- Any extra incoming information from output results of associate services is meticulously inserted to make the model more realistic.
- Validation and justification of the model's efficacy are accomplished through the simulation of a baseline scenario and its subsequent comparison with known results. This initial simulation confirms that the model execution achieves its intended purpose as measured by overall systems and components specific variables.

The PSM suite is an advanced solution which enables complex process simulation and production systems modelling. MFN (Material Flow Network) is an approach that facilitate the modelling of the material, data, and energy flows within varying production chains. This analysis supports users to comprehend efficiency in resource usage as well as its environmental impact, resulting in sound ecological and economic decisions. PSM Hierarchical Inheritance Registry (HIR) contains variable structures that allow developers to build diverse industrial system models to individualise each model to suit the specific needs and requirements, as indicated by the associated stakeholders (both external and internal), of a value chain.

The Plooto holistic solution facilitates PSM, allowing easy access and utilization of its functionalities. This means that processes of efficient modelling such as scenario development and data visualization are also integrated with this application. More so, this platform's simple design enables users to further expand PSM's functionality. Available through the Plooto platform, PSM offers enhanced capabilities and accessibility for users and unique features in various industrial fields, such as:

- **Flexible Systemic Modelling**: Capable of modelling and simulating the entire value chain and related actors.
- **Bidirectional Interactive Models**: Turns process models into active components that interact bidirectionally with physical systems.
- **MFN Principle**: Utilizes MFNs for modelling material, data, and energy flows, making it fundamental for process analysis and evaluation.
- **Multifaceted Integration Capability**: Seamlessly connects with Analytics, Optimization, and other tools, or methods from diverse scientific fields.
- **Advanced Modelling and Simulation Features**: Supports complex process model establishment, graphical representation, data exchange, and real-time visualization.

Through its integration into CRIS, the PSM tool is specially adapted and extended to be tailored to the unique requirements of Secondary Raw Materials domain for each pilot case. This integration emphasizes the tool's adaptability and relevance to the current and any future industry needs. The key functionalities of the PSM tool through its availability from the Plooto platform include:

- **Graphical Model Design**: Users can design models graphically, making the process insightful and user-friendly.

- **Detailed Flow Specifications**: It allows for specifying material, data, and energy flows, ensuring accurate and realistic modelling of industrial processes.

- **Comprehensive KPIs and Reporting**: Users can calculate a variety of KPIs (general, or tailored) for specific processing units, associated parties but also for the overall value chain, with results available in various formats for thorough analysis and easy reporting.

The desktop application of PSM interacts with the Plooto platform's web application back-end through an API (Figure 25). This interaction is essential for uploading and processing industry models and scenarios with various alternative parameters. The PSM tool and the Plooto platform provide API functionality for real-time simulation, monitoring, and on-demand modification of process models. This feature is particularly beneficial for adapting models to varying scenarios and requirements, enhancing the tool's feasibility and sensitivity in real-world cases.

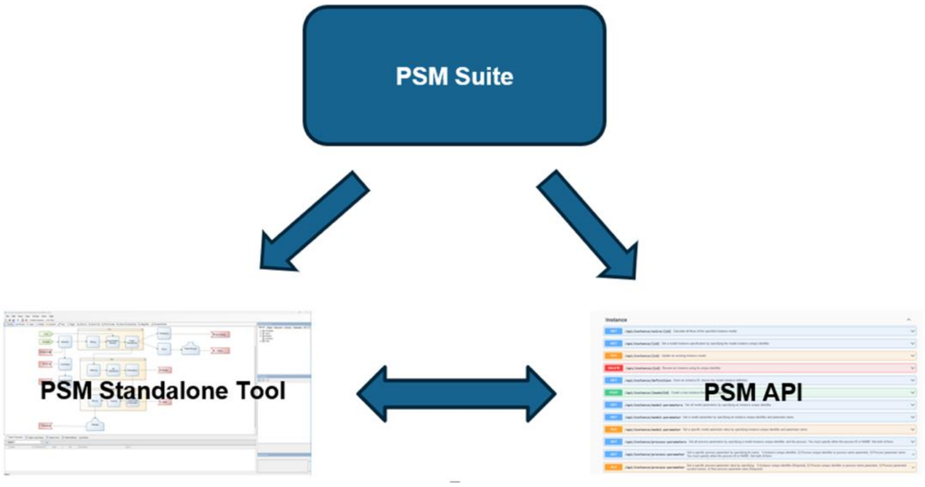


Figure 25: Process Modelling and Simulation Suite API capabilities

5.4.2 Digital Twins (assets and networks) modeller

CRIS embeds MIRA basic functionalities for the modelling of user environment.

The user needs to define the internal processes to be monitored by:

- defining the Digital Assets that represent the objects to monitor and operate. It is also necessary to enrich the asset with its characterizing properties, and the telemetries that will provide data supporting the monitoring phase.
- aggregating the assets in networks that are related to a specific goal, eventually establishing relationships among assets.
- selecting the services to be used (e.g., analytics, simulation, optimization, etc.). To be noted that services become available to be selected and included in the user's system once they are integrated in the platform (see Section 5.7).

The result are *DT process models*. The design of DT process models is based on the corresponding process models (which are implemented in T2.6), but with a more operational goal which allows monitoring and management of the actual process through the execution of services, and the measurement of production-related KPIs through the collection of the corresponding metrics.

Having modelled the processes, the user can define *DT supply chain model*. A supply chain represents a collaboration among different parties that need to come to an agreement about: each partner's roles, responsibilities, and liability, the assets involved in the collaboration, the data to be shared along the supply chain, and the relevant metrics that can be measured to assess the efficacy and the circularity of the collaboration. Such agreements must be maintained in a secure way.

Both *DT process models* and *DT supply chain models are* implemented in Task 2.1, but briefly reported here for completeness.

The process to establish a supply chain consists of the following main phases:

a) Establish the collaboration between the parties that are being interacting
b) Agree on the assets that are shared between the collaborative parties
c) Establish the network (supply chain)

more particularly, for each phase we have the following:

Establish collaboration: Plooto should provide the necessary functionality to establish a collaboration. This means that every partner who is using Plooto should create a list of predefined collaborators with whom they are working with. This fulfils the need for industries to have a formalized way to establish the supply chain with agreed companies and only with those that comply with the internal processes.

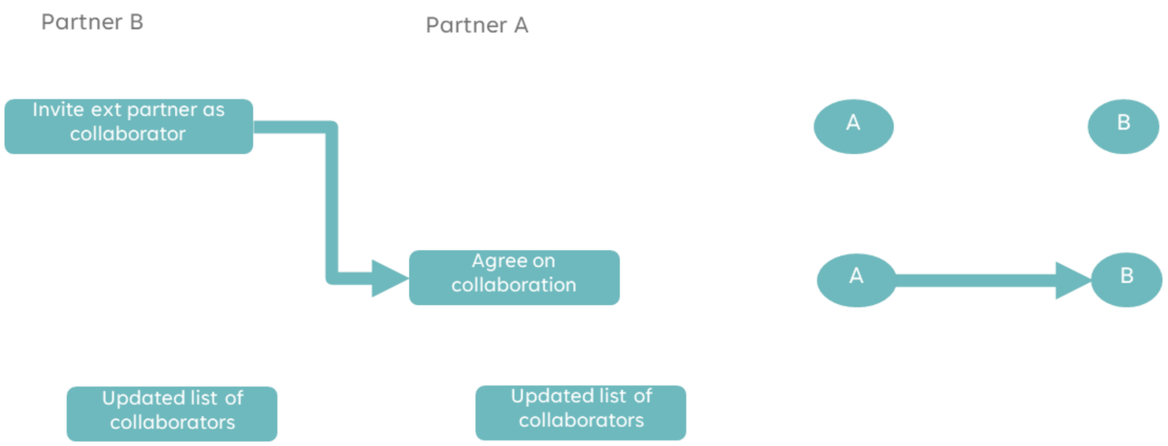


Figure 26: Establishing collaboration

The process for establishing collaboration will be:

- Partner A requests B to become collaborator. In the invitation we can also attach (optional) a file that can be used as a reference agreement for the particular collaboration.
- Partner B agrees and in both Partner A and B there is a record of a new collaborator.

Plooto will also consider negotiation loops, i.e. any partner requiring updates on the description or the agreement for the specific collaboration.

Link shared assets: in a context of a supply chain shared assets will be

- Materials produced by partner A and used as incoming material for partner B.
- Resources (machines) from partner A that can be used (as a service) to partner B

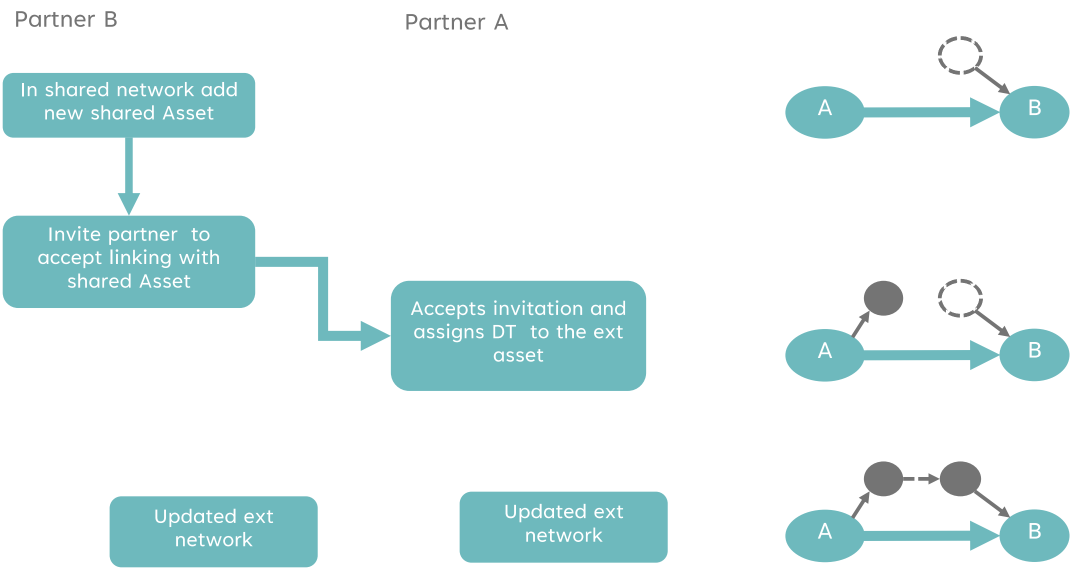


Figure 27: Link shared assets between collaborators

The process for establishing a linked asset will be:

- Partner A requests an external asset from partner B. there should be also an option to send an agreement form about the particular shared asset.
- Partner B gets the request and if agrees assigns an internal asset DT to become as shared asset for A.
- In the particular shared asset, partner B selects which of its telemetries will be used for data sharing.
- Both partners agree on the shared asset details (name, description, telemetries...)
- Both partners will have a shared asset in their records:
    - Partner A will have an *incoming shared asset* with owner Partner B
    - Partner B will have an *outgoing shared asset* for user Partner A

Plooto will also consider negotiation loops, i.e. any partner that requires modifications on the shared asset details (telemetries, terms of use, etc.).

Establish shared network

A shared network is the digital representation of the supply chain. Every partner in a shared network will view only the shared assets and collaborators that he/she is directly linked to.

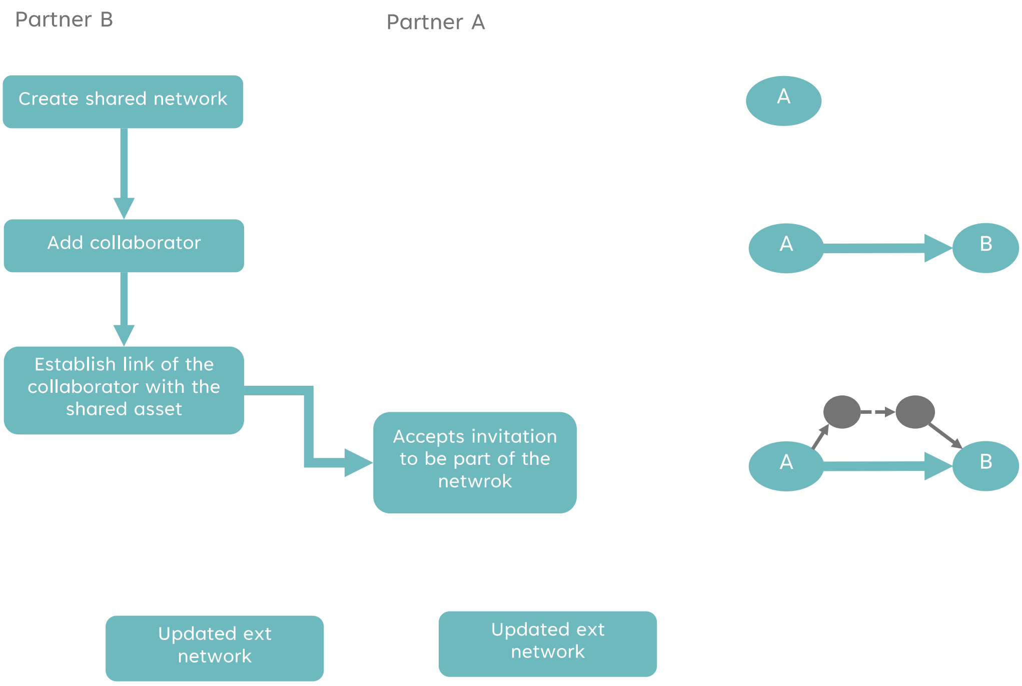


Figure 28: Create links for a shared network

The process to establish a new shared network is the following:

- Partner B creates a new shared network in Plooto
- Partner B selects from the list of collaborators the stakeholders (Partner A) to create the link with B (wither input or output). This can be done also using a graphical way.
- For the particular link, partner B assigned the shared asset (outgoing or incoming).
- Partner A needs to confirm the participation.

The figure below illustrates how the supply chain DT will work on the Magnets pilot case. In a similar way we will model also the rest pilots.

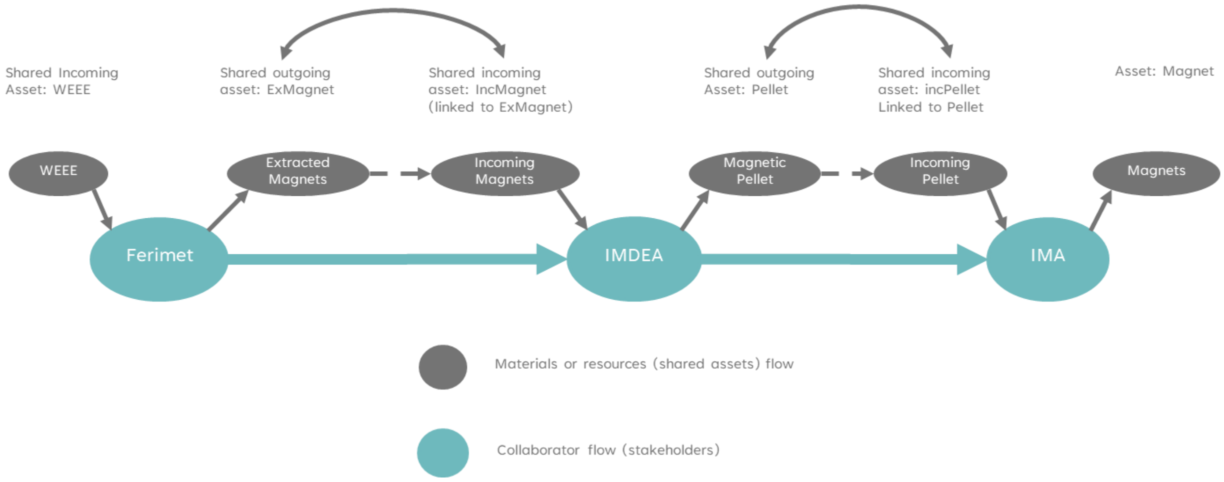
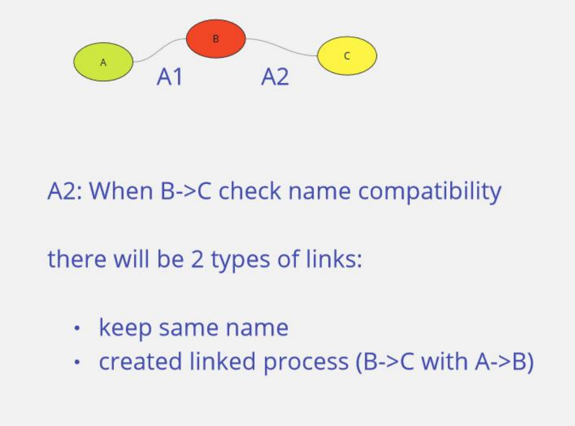


Figure 29: Shared assets flow in the magnets supply chain

If we try to extend our approach to a multiple tier supply chain, this means a distributed way, where network links are established and all of them with a trace of the whole supply chain. For instance, partner B may have already a network with A and needs to integrate it with a new entity C (C invites B to work on a network).

In such case, the partner will have to link the two networks with one of the following options:

- Either to include partner C in the existing network (i.e. keeping the same network id)
- Or create a new network (id: A2) and link A2 with A1.



A2: When B->C check name compatibility

there will be 2 types of links:

- keep same name
- created linked process (B->C with A->B)

The above approach ensures also a distributed approach to supply chain DT. This means that in multiple tier Supply chain, each actor has a view of its direct interactions. For instance, in the supply chain below, company B will have a monitor only of its interactions (with A and C).

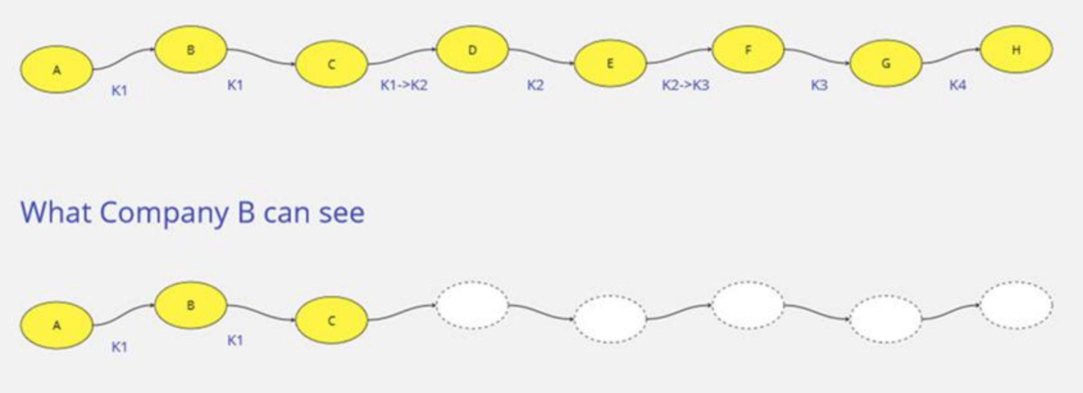


Figure 30: Multiple tier supply chain DT implementation

This approach also is in line with the IDS specifications. It rather extends its functionality where through the shared asset concept industries will have improved visibility of their supply chains, where they participate and what is being shared in each network (materials flows). Through the IDS connectors the data will be shared with regards the shared asset that has been configured and modelled in Plooto.

Once the system is modelled, the user can customize the dashboard to have a complete overview of inter- and intra-company processes, the assets involved, their status, and any critical issue.

The dashboard allows to operate on the system through selected services or specific functionalities.

5.4.3 Sustainability Balanced Scorecard

The Sustainability Balanced Scorecard (SBSC) is designed to serve within Plooto as a monitoring and decision-making tool, structured on the Integrated Plooto Framework presented in D1.3. The Plooto Integrated Framework incorporates the Sustainability and Governance Framework, wherein models, standards and frameworks are analysed, capitalising on successfully tested and validated methods (frameworks and standards) in assessing the value chains' performance over their circularity, sustainability and resiliency.

Building on extensive review of available sustainability standards and frameworks, and on business governance models and data governance aspects, Plooto compiles a robust Framework to build on it the Sustainability Balanced Scorecard. Main pillars of the framework are the environment, society, and governance, incorporating economy and growth perspectives. Although the initial approach of Kaplan and Norton when introducing the Sustainability Balanced Scorecard (SBSC) in 2002, was to present the SBSC as a tool that "*takes into account non-monetary strategic success factors that significantly impact the economic success of a business*" [1], the increasing strategic importance of assessing the companies over their environmental, social, and ethical issues [2], empowers the SBSCs dynamic towards a more comprehensive point of view, especially in relevance to achieve the sustainability and resiliency of industrial value chains.

Critical element in structuring the SBSCs is to define the hierarchy between performance perspectives and strategic objectives of the business. To this end, the SBSC in Plooto is compiled through configurable and personalised visualisations that will support the monitoring and the decision-making processes for each industry. The SBSC integrates the traceability strategies defined_in WP1, the sustainability perspectives derived through the Sustainability Framework and the governance models and data governance, serving as a one-stop-shop in assessing circularity across the industrial value chains. The assessment in SBSCs derives from the monitoring and measurement of selected KPIs that comprise **sustainability** (carbon footprint, resources, pollution, LCA), ***society*** (human capital, product assessment, stakeholders, opportunities), ***governance*** (corporate governance, corporate behaviour, litigation risks and corruption), and economy and **growth** (financial, customer, growth perspective), alongside with a group of pilot-related KPIs, aiming to serve as a configurable and personalised tool for each of the investigated industrial value chains. Especially for the aspect of Lifecycle Assessment, reliable LCA tools/methods will be integrated into the SBSC, aiming to underline the elements/operations across the value chain that impact on the overall process performance and to showcase and evaluate this performance, indicating the points for improvement (i.e., processes, techniques, approaches, etc.) and the potential arisen opportunities per value chain.

5.5 Services

5.5.1 Service gateway

The service gateway is a logical block introduced as a single access point to act as a proxy for multiple services. Therefore, It receives the requests from the core service and forward it to the invoked service. The envisaged types of services are described hereafter.

5.5.2 Analytics

Analytics services in Plooto will be complementing process simulation and optimization services, particularly when dealing with intricately complex processes that are impractical to model through conventional approaches. The analytical framework is expected to align with the principles of the big-data lambda architecture, with a specific emphasis on separating real-time model deployment from the model development process within the batch pillar of the architecture. This segmentation ensures that the analytics services can operate efficiently and effectively, responding to dynamic real-time data while continuously improving models in a more controlled batch environment.

Analytics will be developed in Task 2.4 and envisions the following services to be provided:

1. **Data Cleaning Service (Expanded Anomaly Detection Service)**: This service will be used to ensure data integrity and reliability. This expanded anomaly detection service will play a vital role in refining the quality of input data, thus enhancing the overall accuracy of subsequent analytics processes. **Envisioned integration:** The data cleaning service will be seamlessly integrated with the data adapters within the Plooto platform. This integration aims to ensure the provisioning of clean data or insights regarding anomalous data at the point of data storage or utilization within the Plooto platform. In practice, this means that the data cleaning service will operate in conjunction with data adapters, guaranteeing the quality of data within the platform.
2. **Predictive Services:** Predictive services will be at the core of our analytics framework, offering predictive modelling capabilities (regression or classification). These services will be built on traditional machine learning techniques as well as on innovative graph-based methods. They will empower decision-makers with insights into future trends, potential issues, and optimization opportunities within the complex manufacturing and supply chain processes. **Envisioned integration:** The predictive services will be integrated as stateless components, exposing their functionality through an API, where API calls will provide the whole context for the predictive service. Alternatively, they can also be integrated directly into the data processing pipeline. This integration approach will enable continuous assessments of the production process. The predictive services will receive real-time data, either from a database or via a pub/sub mechanism, and deliver results in a similarly online fashion. This real-time integration ensures that the production process is under constant assessment and allows for prompt decision-making.

3. **Recommender System:** A recommender system will be integrated to identify and recommend novel opportunities within the manufacturing process, thereby enhancing efficiency and productivity. However, it's worth noting that the usability of the recommender system is still undergoing investigation, contingent on the specific needs and intricacies of the Spanish pilot. This adaptive approach ensures that the recommender system is tailored to meet the precise requirements of the pilot, maximizing its effectiveness. **Envisioned integration:** The recommender system is envisioned as a standalone component, primarily relying on static data provided during the design phase. This system will operate independently, drawing upon predefined data to make recommendations. Its integration strategy is designed to be static, ensuring that it functions efficiently based on the initial data provided.

In summary, the integration of these services within Plooto will be tailored to their specific functions and requirements. Data cleaning will work seamlessly with data adapters to maintain data quality, predictive services can be integrated as stateless components or within the data processing pipeline to offer continuous assessments, and the recommender system will operate independently, leveraging static data for recommendations. These integration approaches will have to be further aligned with the objectives/requirements of Pilots.

The proposed analytics solution will provide a comprehensive distributed approach to data analysis across different stages of value chains. The analytics service will be working in tandem with the organizational Digital Twins, adding value to the virtual representation of the physical processes and assets. This integration allows for an expanded analysis, simulation, and optimization of the processes. The service will also be cloud-enabled, offering scalability, flexibility, and reliability, while containerization will guarantee the portability, scalability, and compatibility of the proposed solution.

5.5.3 Process Modelling and Simulation

PSM suite is a comprehensive solution for simulation that provides highly specific functionality while remaining secure and user friendly. The suite comprises the PSM Tool, which is a standalone desktop application; the PSM Online Service (accessible through HTTPs API) which also plays essentials functions throughout the process. PSM is a front-end interface built upon the .NET framework and Visual Basic and C# languages used in developing the PSM tool which will be used by the user. It has user centric design that comprises different elements for smooth model management, editing, as well as specifying properties. This tool is standalone and as such, it suits academic and research purposes within the non-commercial setting.

The PSM Online Service complements the standalone tool, enabling broader and more dynamic interaction with the PSM suite through an HTTPS API. This facilitates the integration WITH external systems and platforms:

- **API-Driven Interaction:** The HTTPs API allows external systems and users to access the PSM tool, allowing for remote creation and manipulation of simulation models.
- **Asynchronous and Secure Communication:** Users can safely submit alternative simulation scenarios (jobs) and come back later for acquiring the results.

As for the data handling and integration aspect, the PSM tool adopts a fortified and secure approach, characterized by the usage of contemporary security protocols such as SSN (Secure Socket Network) and HTTPs (Hypertext Transfer Protocol Secure), which are instrumental in ensuring the safe storage and reliable execution of simulation models within the PSM local server. By leveraging such protocols, the PSM tool ensures the security of sensitive data while also enhancing the overall reliability and robustness of the suite.

- **Local Server Storage:** The PSM suite is designed to store the data on a local server, ensuring that each desired model can be executed at any time, adding an additional layer of security and reliability.
- **On-Demand Model Execution:** Provides users with significant flexibility, especially in cases where timely and accurate simulations are critical for decision-making or operational management.

5.5.4 OptEngine - Optimisation

OptEngine works as a shell around the optimization. Its architecture follows an asynchronous approach and is agnostic to optimization-specific data requirements. That is, optEngine receives, stores, and forwards the optimization data to the optimization service requested by the end-user.

Optimization requests along with the respective data are received via a web API. This API allows the actions described in the previous section. The communication with the API requires authentication, is encrypted (https) and asynchronous, i.e., once an optimization job is submitted, the callee does not wait for its completion.

Data stores within optEngine work in a twofold manner:

- **Permanent storage** via a database (DB): this is where optimization requests and the related data are permanently stored or retrieved and updated when necessary.
- **Temporal storage** via the use of queues: this is where optimization data is stored up to the point where they get consumed by the optimization services that read these queues.

Regarding the optimization data, both the DB and the queues are data-agnostic following a general JSON schema. This allows the storage, permanent and temporal, of different data structures required from different optimization services.

The employed queues allow the asynchronous processing of an optimization job. Additionally, by being durable they ensure that when optEngine or an optimization service fails, the job along with data are available in the respective queue. This means that optEngine, upon reception of a new optimization job, forwards it to the requested optimization service via a queue. Each optimization service listens for a new optimization job to a specific queue and writes status/progress updates to another queue. Last, optEngine listens to (a) a queue for status/progress updates and (b) multiple queues for optimization results.

The flow of data and the architectural approach of optEngine are depicted below.

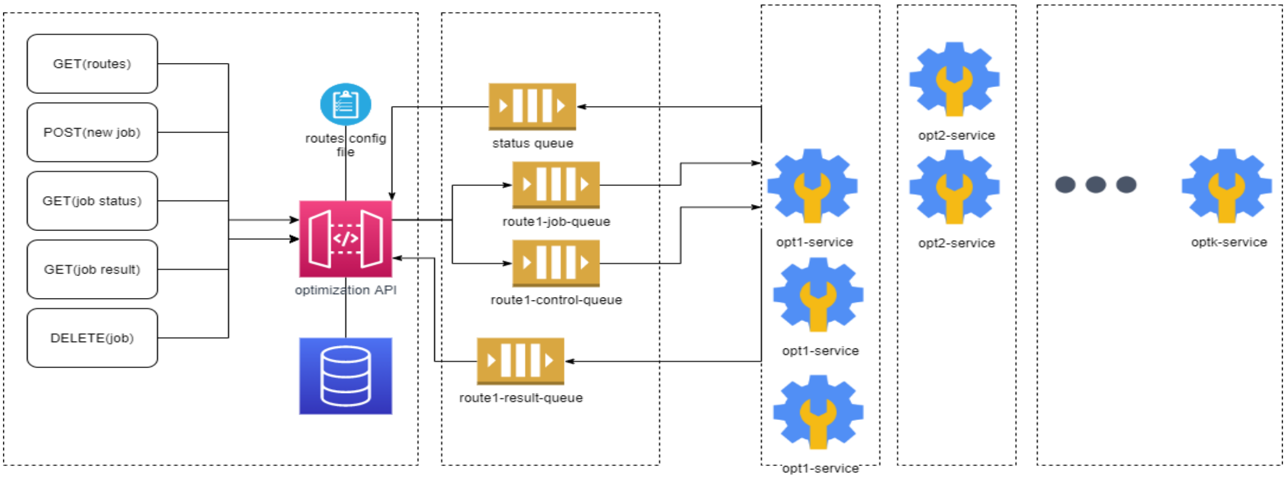


Figure 31: Optimization approach and data flow

5.5.5 Life Cycle Assessment

The Life Cycle Assessment (LCA) is a methodology used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle. This assessment considers various life cycle stages: from raw material extraction, production, use, to disposal or recycling. The main goal of an LCA is to understand the environmental hotspots and potential areas for improvement, in order to minimize negative impacts. The scope of an LCA involves defining the system boundaries, which means determining what stages of the life cycle will be included in the assessment. It could encompass everything from cradle to grave (entire life cycle) or cradle to gate (until the product leaves the factory), depending on the specific goals and constraints of the analysis. The scope also involves identifying impact categories to assess, such as carbon footprint, water usage, or toxicity.

The role of LCA within Plooto is to assess the environmental performance of the waste valorisation line in the Greek pilot (ASPIS production plant) and demonstrate the environmental benefits of process optimization for energy preservation. The outputs of the LCA analysis will be incorporated in the product passport of the produced molasses and can also be made available to platforms derived and composed during the project's lifetime.

5.6 Digital Product Passport

The Eco-design Directive 2009/125/EC and proposed modifications[11], establish a framework to set eco-design requirements for specific product groups to significantly improve their circularity, energy performance and other environmental sustainability aspects. It aims to enable the setting of performance and information requirements for almost all categories of physical goods placed on the EU market.

The framework will allow for the setting of a wide range of requirements, including on: a) product durability, reusability, upgradability and reparability; b) presence of substances that inhibit circularity; c) energy and resource efficiency; d) recycled content; d) remanufacturing and recycling; e) carbon and environmental footprints; and f) information requirements.

In line with the regulation, the DPP shall provide information about products' environmental sustainability (i.e., framework requirements). This information will be easily accessible and it will help consumers and businesses to make informed choices when purchasing products, facilitate repairs and recycling and improve transparency about products' life cycle impacts on the environment. Additionally, it shall enable to electronically register, process and share product-related information amongst supply chain businesses, authorities and consumers, which is intended to help public authorities to better perform checks and controls, create transparency, unlock circularity, and enable future and sustainable economic growth[12] [13] [14] [15].

Plooto aims to set the foundations for the DPP in the three domains of the pilots. First of all, it is necessary to fill the information gaps along the supply chain, which are partially obscuring the actual footprint of a product, and to guarantee traceability throughout the product's life cycle.

In relation to the types of data to be included in the DPP and how to structure it, Plooto has looked at current initiatives, such as Product Circularity Data Sheet (PCDS)[16] or the Global Battery Alliance (GBA)[17].

Plooto will consider a generic approach to the DPP. This means that the platform should incorporate the necessary functionalities so that supply chains can model their own DPP format

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[11] http://data.europa.eu/eli/dir/2009/125/oj

[12] https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?reference=2022/0095(COD)&l=en

[13] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13682-New-product-priorities-for-Ecodesign-for-Sustainable-Products_en

[14] https://www.europarl.europa.eu/RegData/docs_autres_institutions/commission_europeenne/com/2022/0142/COM_COM(2022)0142_EN.pdf

[15] https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products-regulation_en

[16] https://pcds.lu/pcds-system/#glossary

[17] https://www.globalbattery.org/action-platforms-menu/pilot-test/

and monitor its execution and sharing in the operation phase. In principle, the DPP will consist of the following types of information:

- Textual information: about product, origin and anything that the company want to incorporate into the DPP.
- System Information coming from sensors, services or other sources: this information will be integrated through the telemetries monitored inside Plooto.

The proposed structure for Plooto DPP is represented in the following figure. The corresponding structure for the three pilot has already been defined and it is reported in Appendix B.

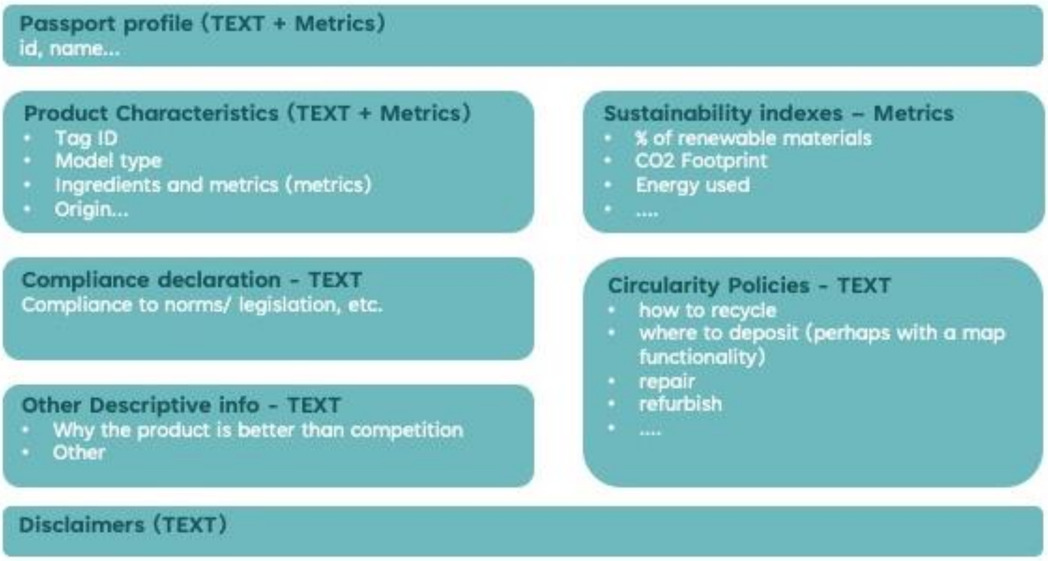

Figure 32: Plooto DPP data structure

The DPP needs to provide useful data to those who handle the product at the end, therefore it must to be generated incrementally, adding data corresponding to individual components and material as it passes along the chain.

Therefore, when detailing the collaborations along the supply chain (see 5.4.2), the DPP corresponding to the (semi-)final product transmitted should be included among the agreed data shared.

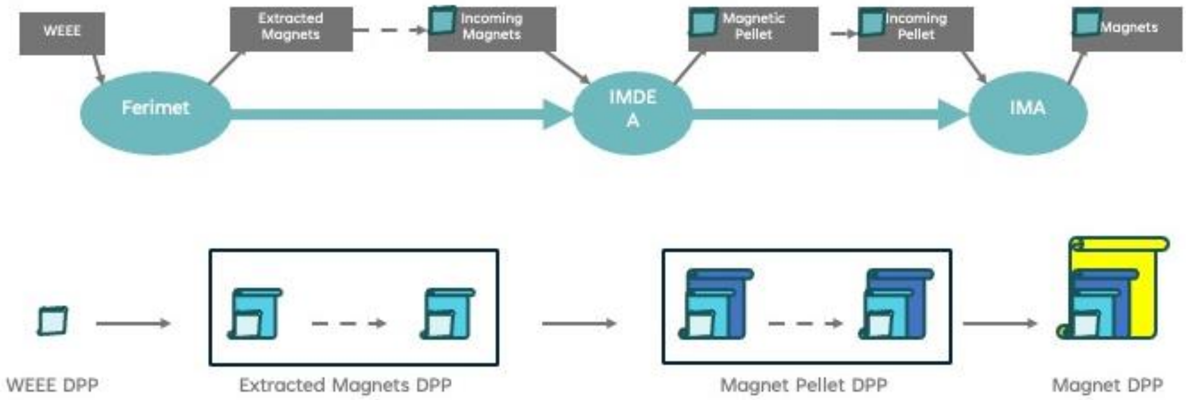

Figure 33: Linking assets with DPPs in value network

From an operational point of view, it means to link the shared asset and DPP in the value network. As it can be seen in Figure 33, the final DPP links all the DPPs from previous steps, in this way it is possible to ensure traceability and assess the actual footprint of the final product.

Having modelled the supply chain as networks of DTs ensures the possibility to collect the necessary information that will be included in the passport from the corresponding (shared) assets and production telemetries.

Figure 34 provides a graphic overview of both business and operational actions of DPP implementation.

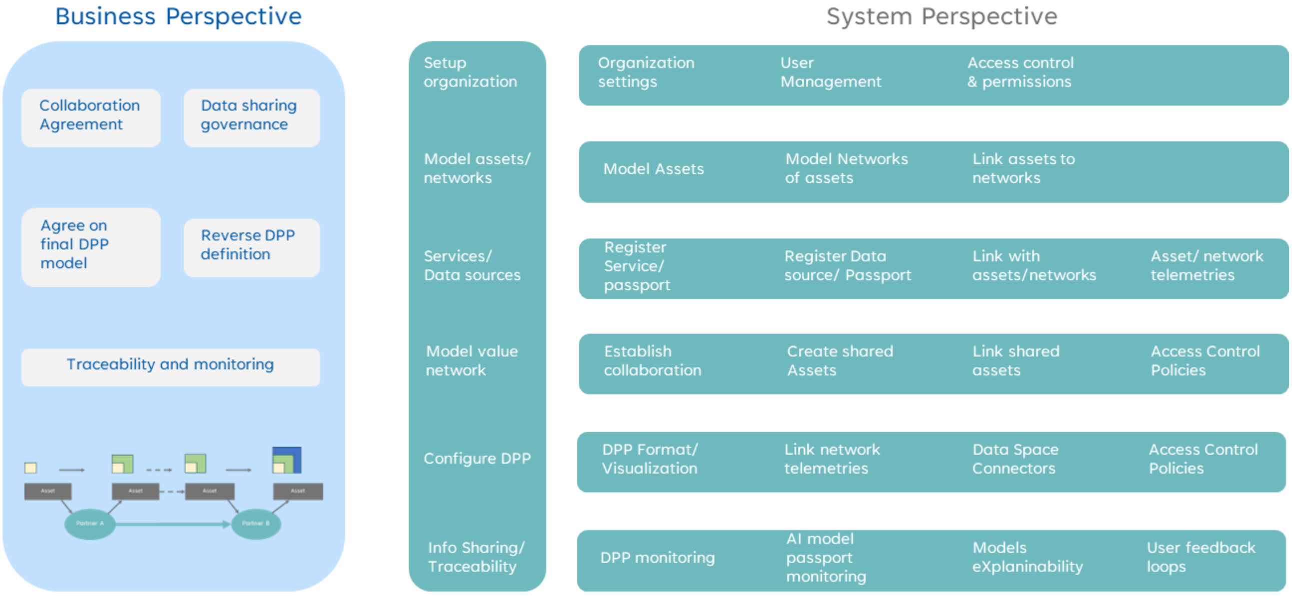

Figure 34: DPP main ICT framework and usage scenarios

The **business perspective** summarises the actions to be performed at business level to establish the value chain. These include definition of the collaboration agreements, but also the identification of the data to be share along the supply chain (in compliance with Plooto data governance) and the definition of strategies for traceability and monitoring along the supply chain.

The **system perspective** details the actions to be carried out on the platform. Here the three bottom groups of functions are specific of the value chain and allow to model the supply chain as described in Section 5.4.2, configure the DPP, and define the data sharing and traceability strategies. These features will be implemented in Task 2.1.

The DPP will be securely stored (blockchain) and made available through readable artefacts (e.g. link in a web page, QR Code, etc.) and depending on the case).

5.7 Approach to integration

In Plooto's vision, CRIS is the comprehensive environment that allows the use of several technologies that are not necessarily homogeneous. The *technologies* to be included span from APIs, Web Services (WS), data streams, and tools. The guidelines to their integration is briefly outlined below.

Data Streams - Feeds directly into the RabbitMQ → consumed by the analytics service, mapped into one (or more) asset(s) feeding the corresponding telemetries

APIs/Web Services - Need to be implemented in a way that produces output in a format that can be directly digested by the platform (like data streams). Otherwise, it is necessary to implement an adapter that consumes data coming from APIs, converts it to the expected format and pushes it into the dedicated queue.

Tools – from integration perspective, tools should be regarded as a coherent system that serve a specific goal (i.e., to create/modify a process model) and have their own user interface.

To make such tools available through CRIS the iFrame mechanism will be used. Users are authenticated and authorised by CRIS, which will pass a token to the iFrame to ensure the compliance with the roles and policies defined by the organization in charge. The adapter serves to synchronize the application contained in the iFrame with the user credentials and other relevant data.

Additionally, to ensure the long-term sustainability of the platform after the project end, it is essential to be able to establish supply chains with stakeholders outside of Plooto. These will have their own IT infrastructure and might not be interested in adopting CRIS. In that case, on top of the patterns described above, it will be possible to ensure the connectivity and data sharing via Plooto-IDS connector.

6 Conclusions and next steps

This document is the first version of D1.5. it will be updated and integrated in the final version that will be released at M24.

In the final version, we plan to:

- Assess, refine, and validate the requirements
- Detail the architecture specifying the flows among components
- Integrate the different services and tools
- Create and securely store DPPs in compliance with EU regulations

References

[1] Figge F., Hahn T., Schaltegger S, Wagner M. (2002), The Sustainability Balanced Scorecard-Linking Sustainability Management to Business Strategy, Business Strategy and the Environment 11, 269–284, DOI: 10.1002/bse.339

[2] Hansen E., Schaltegger S. (2016), The Sustainability Balanced Scorecard: A Systematic Review of Architectures, Journal of Business Ethics, 133:193-221, DOI: 10.1007/s10551-014-2340-3

Appendix A: Introduction to IMF – guidelines[18]

System

The concept of system lies at the core of IMF. We will use the following definition. *A system is a group of connected elements that interact through media to provide one or several functions, where:*

- *A function is understood as a capability to realise an activity*
- *Like the system itself, also its elements, called system elements, provide functions; the system elements functions are called sub-functions of the system;*
- *A medium is understood to be either material, energy, force, or signal carrying information;*
- *Both the system and its system elements have terminals;*
- *Two system elements are connected via connecting a terminal of one system to a terminal of the other; the point at which the terminals connect is called a connection point;*
- *The set of connection points connecting terminals of one system to terminals of another is called the interface between the two systems;*
- *System elements of a system connect to elements outside the system boundary in the same way as they connect to system elements within the system boundary*.

Engineered System

An engineered system is designed with a purpose; the purpose is served by one of the system functions called the main function. Engineered systems whose main function is to transform a state of media at input terminals to a state of media at output terminals are of particular interest to IMF.

This definition is closely reflecting the definition in the Systems Engineering standard ISO/IEC/IEEE 15288, where a system is defined as a combination of interacting elements organized to achieve one or more stated purpose. Figure 35 graphically illustrates the definition in ISO/IEC/IEEE 15288.

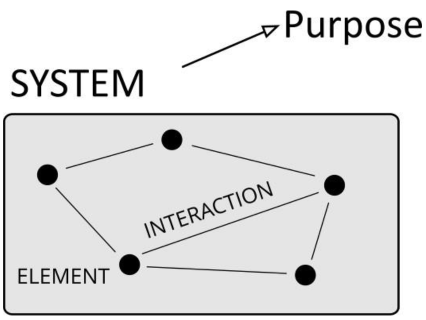

Figure 35: The system concept from ISO/IEC/IEEE 15288

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[18] https://sirius-labs.no/imf/

Recursive Pattern

The concept of systems comprises a recursive pattern:

- The system elements of a system can themselves be systems; this results in a system breakdown
- System elements can connect to elements outside the system boundary, and these elements can themselves be systems and be elements of systems; this results in a topology
- These system breakdown and topology principles can be combined in a recursive matter

The points are substantiated in the following using a cooling system as an example. The elements of a cooling system may be artefacts such as pumps, pipes, chillers, etc. The purpose of the cooling system is to deliver heat exchanging. The main function of the cooling system is thus to provide a heat exchange function.

Breakdown

The system *breakdown* describes how a system is drilled down to system elements recursively. A complex system element of a system may be considered as a system with its own system elements (Figure 36

). This view of a system can be applied recursively, with system elements being drilled down into sub-systems until a desired level of detail is achieved. The process of drilling down a system element of one system to a system with its own system elements is called a *system breakdown*.

For example, a cooling system for an oil and gas facility might consist of a circulation system for the cooling medium and a heat exchanger with seawater supply. The circulation system can be drilled down into a set of circulation pumps, distribution headers and cooling medium expansion tank. All these system elements in the circulation system can be further drilled down in new system breakdowns (e.g., cooling medium expansion tank system consists of valves and instruments).

The desired granularity of breakdown might vary between the different parties involved in the engineering of a facility asset. For instance, the engineering contractor may take the pump as an artefact that serves as a system element, while the pump supplier needs to view the pump as a system and perform a further system breakdown. Note that since the system elements of a system comprise a group, a breakdown is also a way of grouping. The notion of granularity will be extended in future versions of the IMF manual.

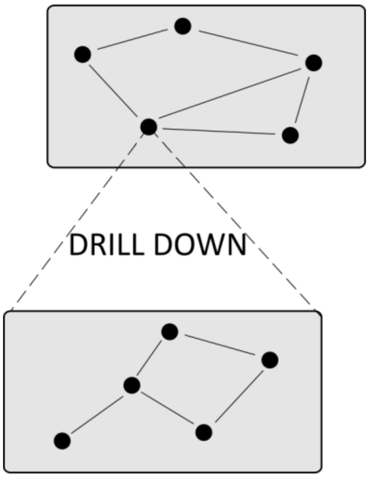


Figure 36: Illustration of a system breakdown

Topology

A systems *topology* describes how system elements are interconnected and hence how they interact. In IMF it is assumed that system elements interact through media, i.e., material flow, energy, force, or signal.

Different disciplines will typically address different media. Process engineers may, for example, be interested in how the liquid and gas flow between system elements. The topology within a process system may hence be focused on these types of media. An electrical engineer will be interested in how the electricity flows between the system elements and design the topology of an electrical system accordingly.

A complex system typically involves interaction from different disciplines. This system can be broken down into sub-systems where in each system elements interact through only one single media type. This situation is illustrated in Figure 37 The interface between the systems specifies how the systems interact.

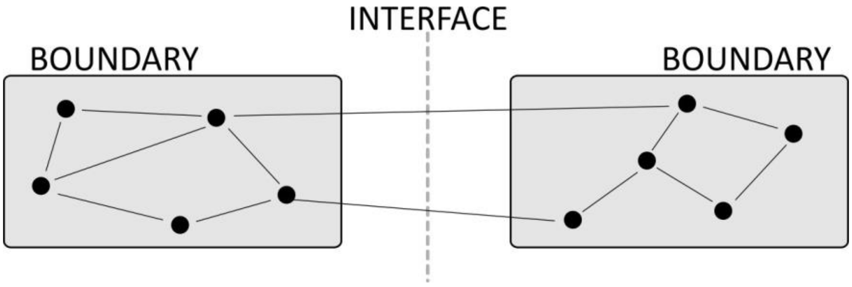


Figure 37: Illustration of the interaction of system elements inside and outside of system boundaries.

In the cooling system example, the pump and the heat exchanger interact by means of the cooling medium that the pump pumps to the heat exchanger. The circulation pump is connected to an electric supply; thus, the cooling system interacts with the electrical supply system of the facility.

Combining Breakdown and Topology

A repeated use of the principles of system breakdown and interaction gives rise to similar patterns recurring at progressively smaller scales both vertically (system breakdown) and horizontally (system interactions). The pattern is illustrated in Figure 38.

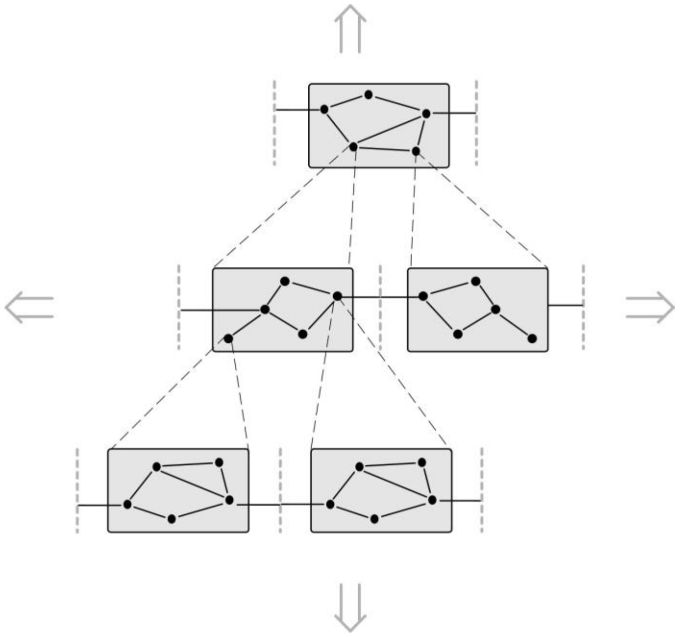


Figure 38: Illustration of system breakdown and topology.

Describing Systems through aspects

In engineering practice, it is natural to describe systems from different points of view, typically from the views of physical artefacts, activity, and location. IMF is a language designed for describing systems from such different points of view, which we refer to as “aspects”. The notion of aspects is essentially the context of modelling that needs to be clarified before modelling, e.g., whether it is about the physical artefact or about the activity, what the purpose of modelling is, and who the users are. Note that the aim of IMF language is to describe systems, not to define systems.

Definition: In IMF an Aspect is defined by specifying the following triple: <Perspective, Interest, Modality>.

Perspective

A *perspective* refers to a particular view of a system or system element. The IMF manual mainly addresses the following perspectives (Figure 39) and allows extension by users:

- *Activity* is to view the system from the perspective of the activity that a system performs or is designed to bring about;
- *Artefact* is to view the system from the perspective of physical objects or software;

- *Location* is to view the system from the perspective of the geometry, or position (geographical position).

Closely related to the activity perspective is the perspective of system Function, referring to the capability of a system to bring about an activity. This concept is fundamental in systems design. The concept of *function as activity* are a dualism of intended versus actual, and frequently discussed together. The names for perspective reflect class naming in the Industrial Data Ontology (IDO).

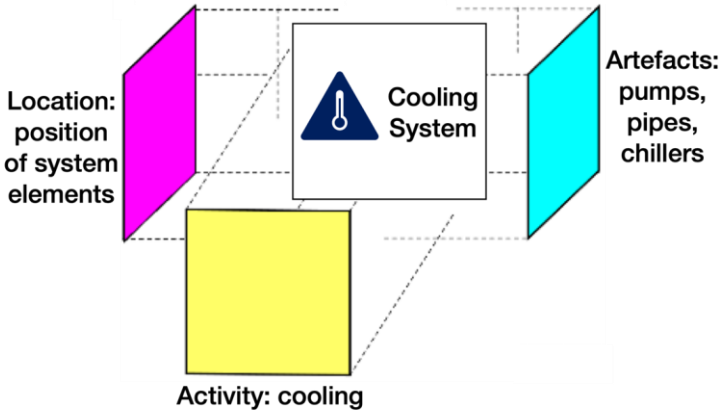


Figure 39: The same system is viewed from different perspectives

For example, from the perspective of artefact, a cooling system is a set of physical objects, such as pumps, pipes, and chillers. From the perspective of activity (function), the function of the cooling system is to realise a cooling activity. From the perspective of location, each artefact system element has a position in and a geometric extension.

Interest

The *interest* is the modelling purpose; it points to the intended usage of the information, the users of the information and their preferences and working habits. The categorisation of interests points to the different stages of the lifecycle of engineering systems, such as system design, detailed engineering, requirement engineering, manufacturing, procurement, commissioning, built, operation, maintenance, disposing, etc. Since the interest contains the information of purpose, usage, and users, it also provides principles of system modelling with breakdown and interaction, and hence how the system elements will be hierarchically grouped and broken down, and how the interactions shall be understood.

Each interest will be further elaborated in future versions of the IMF manual, and aligned to a system lifecycle ontology introduced in the future.

Modality

The *modality* tells if a set of information about engineering systems is a *requirement* or an *intended solution* of the requirement, or it is an *actual solution*. The modality deals with two dualisms, the *intended* versus *actual*, and *requirement* versus *solution*, where a requirement is always intended, thus resulting in three modalities:

- *Requirement* is to specify the intended system requirements, e.g., the functional requirements from the clients;
- *Intended Solution* is to describe the intended solution for a set of requirements, e.g., the product plan from the supplier;
- *Actual Solution* is the actual solution for the requirements, e.g., the actual installed artefacts in a factory.

Important to note is that the same set of information can be requirement for some group of information user, and at the same time intended solution for another group of information users. For example, if the interest is procurement, the client A provides the datasheet about some product to specify the required product (requirement). Then the supplier B provides the datasheet about some product based on some product catalogue that the supplier B can deliver (intended solution). The datasheet with the modality requirement will be verified against the datasheet provided with the modality intended solution. The later one then can serve as the requirement for the internal units of the supplier B, or the supplier C of the supplier B.

The evolving of information of the three modalities typically follows that in Figure 40: for the initial requirement an intended solution is proposed; then both of them are evolved to the revised requirement in the next stage, for which again an intended solution is proposed; this revision repeats until at the end an actual solution is installed.

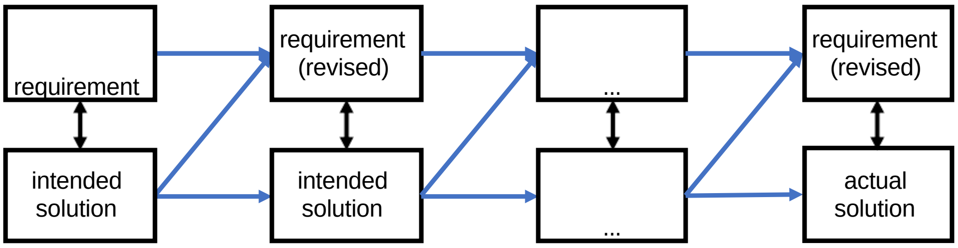


Figure 40: The three modalities and a typical evolving flow

Reserved Aspects

The IMF manual uses reserved names for the following four aspect definitions:

- Function Aspect = <Activity, System Design, Requirement>
- Product Aspect = <Artefact, Built, Intended Solution>
- Location Aspect = <Location, Geometry and Position, Intended Solution>
- Installed Aspect = <Artefact, Built, Actual Solution>

Each aspect has a colour assigned. The colours are included in Figure 39 and are used in later figures to indicate the belonging aspect. Figure 41 illustrates these aspects as being different perspectives on the information about an intended pumping activity.

- The *Function Aspect* (yellow) ❶ is to specify the intended activity, e.g. the information about activity, performance, and function about a pump.

- The *Product Aspect* (cyan) ❷ is to specify the intended solution of a set of physical artefacts to perform the activity, e.g., the information about the physical artefacts of the pump.
- The *Location Aspect* (magenta) ❸ is to specify the geometrical and positional information of the intended solution, e.g., the size and shape of the specified pump.
- The *Installed Aspect* (dark blue) ❹ is to describe information about the actual solution, e.g., the serial number, run hours, and status of an actual pump installed in a plant.

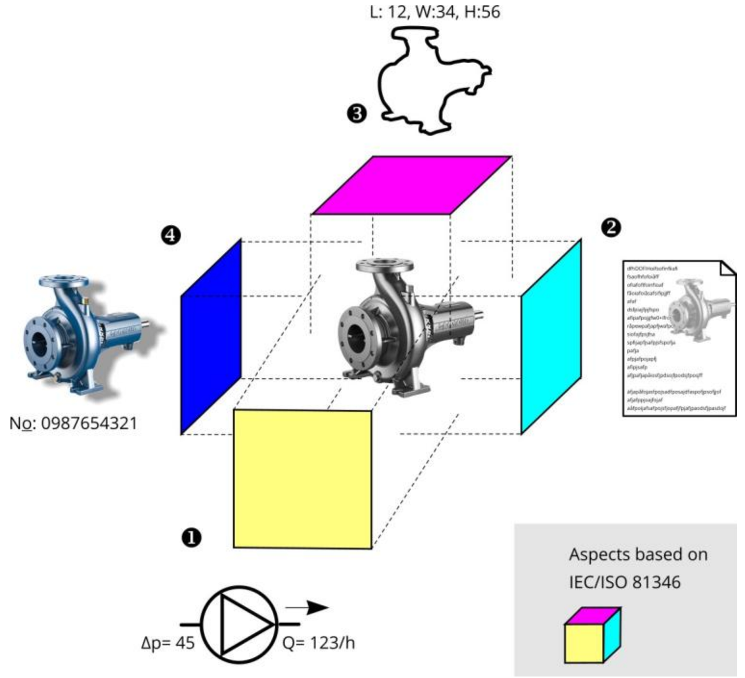


Figure 41: Illustration of the four reserved aspects

Table 5: Definition of the four aspects and their prefixes and colours

Aspect	Definition	Prefix	Color
Function Aspect (F)	The functional requirements to the intended activity	=	yellow
Product Aspect (P)	The intended solution of physical artefacts	-	cyan
Location Aspect (L)	The geometrical and positional information of the intended solution	+	magenta
Installed Aspect (I)	The description of the actual artefacts installed in industrial facilities	::	dark blue

A core concept of ISO/IEC 81346 is the notion of an aspect. IMF borrows this concept, but both widens it and makes it more specific. The IMF concept is wider than the aspect concept in ISO/IEC 81346 because it also addresses the individuals of a facility. ISO/IEC 81346 explicitly states that the standard only addresses so-called occurrences, which can be viewed as tag objects that are distinct from individuals. Also, IMF makes the topology more explicit than it is in ISO/IEC 81346. The IMF concept is narrower in the sense that an aspect is a specific information structure. Also, in contrast to ISO/IEC 81346, IMF does not treat a type as a distinct aspect.

Syntax and Interpretation

IMF is a framework that consists of a family of languages. In IMF a language specification consists of:

- A syntax that prescribes what counts as admissible expressions in the language. The syntax can be specified formally, so that it can be parsed by computer programs, or informally so that humans can understand how to write expressions in the language, possibly allowing some degree of freedom in exact ways of how to write them; such syntactical freedom is unproblematic as long as it does not compromise clarity;
- An intuitive interpretation (typically informal) aimed at users of the language. This interpretation should contain sufficient explanation so that the users understand how to express their use cases in the language and how to understand use cases that others have expressed in the language;
- A formal interpretation that captures the meaning of the language in terms of mathematically precise structures. Formal interpretations of IMF will be specified by translation into logical languages that have a precise formal (i.e., set theoretic) semantics, such as OWL.
- In order to be useful in practice, the IMF languages will need translations to other languages (typically formal languages) that preserve syntactical structures. We refer such translations as structure preserving translations. If the source language and the target language have different structures, such translations are difficult to specify.

All languages in the IMF family are object languages. Hence this section briefly reviews the terminologies of object languages.

Object Language and Object Model

An object language consists of

- Mechanisms for creating *objects*, including mechanisms for giving the objects a unique identifier;
- Mechanisms for attaching *attributes* to objects;
- *Relations* that connect objects. Typically, we discuss *binary relations* where a relation exactly connects two objects.
- Mechanisms for creating *relationships*, which are instances of relations.

An object model is an instance of an object language, consisting of a set of expressions that specify objects, attributes or relations. For example, the following is an object model:

- A set of objects attached with tag numbers (i.e. identifiers) created by a tag master process that ensures unique tag numbers;
- Instances of the relation mountedOn. If t1 and t2 are tag numbers, mountedOn(t1,t2) is a relationship in the model.

A model with only binary relations can be naturally transformed to a directed graph, where objects are nodes, and relationships are edges between the objects.

IMF as Object Langauges

In IMF, objects are called elements. Elements are created from types in analogy with the way that objects in object-oriented programming language are created for execution of a computer program.

It is useful to enrich an object language with classes ordered in a classification hierarchy. IMF also has hierarchies of types similar to classification hierarchy, but a type in IMF is not the same as a class as typically used in formal languages such as OWL: IMF types are constructive, and used to reuse patterns and create elements. Classes are essentially constraints used to classify elements.

Visual Syntax

IMF models are meant to be developed by engineers by manipulation graphical forms using applications. For this reason, IMF has a visual syntax. While the precise syntax supported by an application is left for the specification of that application, the visual syntax used in this manual exemplifies how this can be done.

Displayed elements of an IMF model are blocks and terminals, while relationships between them are displayed using lines just as one would display binary relationships as edges in a graph.

This syntax will be extended so that the lines can hide an object, called an association point. In this way we can associate attributes to a relationship, and also relations to other elements.

Formal Syntax

The formal syntax of IMF is expressed in the ontology languages OWL and SHACL, both standardised as W3C recommendations.

Formal Interpretation

The formal interpretation of IMF is defined by a translation that maps IMF models into models in the language of the Industrial Data Ontology, IDO. In this translation an element (i.e., a block or terminal) in an IMF model is mapped to

- An OWL class restriction if the modality of the aspect of the element is Requirement or Intended solution;
- An OWL individual if the modality is Actual solution.

The interpretation will map information about the same system that is spread over several elements into one system object and adjust domain and range of relations. Note that the notion of a system is a concept in IDO, but not in IMF.

The formal interpretation is essential for integrity checking of an IMF model. This can in many cases be efficiently implemented using reasoning over the IDO interpretation of the IMF model at hand.

Language Elements Overview

The IMF language consists of

- Aspect elements
- Binary relations between aspect elements

Aspect elements in an IMF model have been created as instantiations of types and relationships between aspect elements inserted as instances of relations. Figure 42 provides an overview of terms and symbols in the IMF language. Note that the lists Association Point as an element.

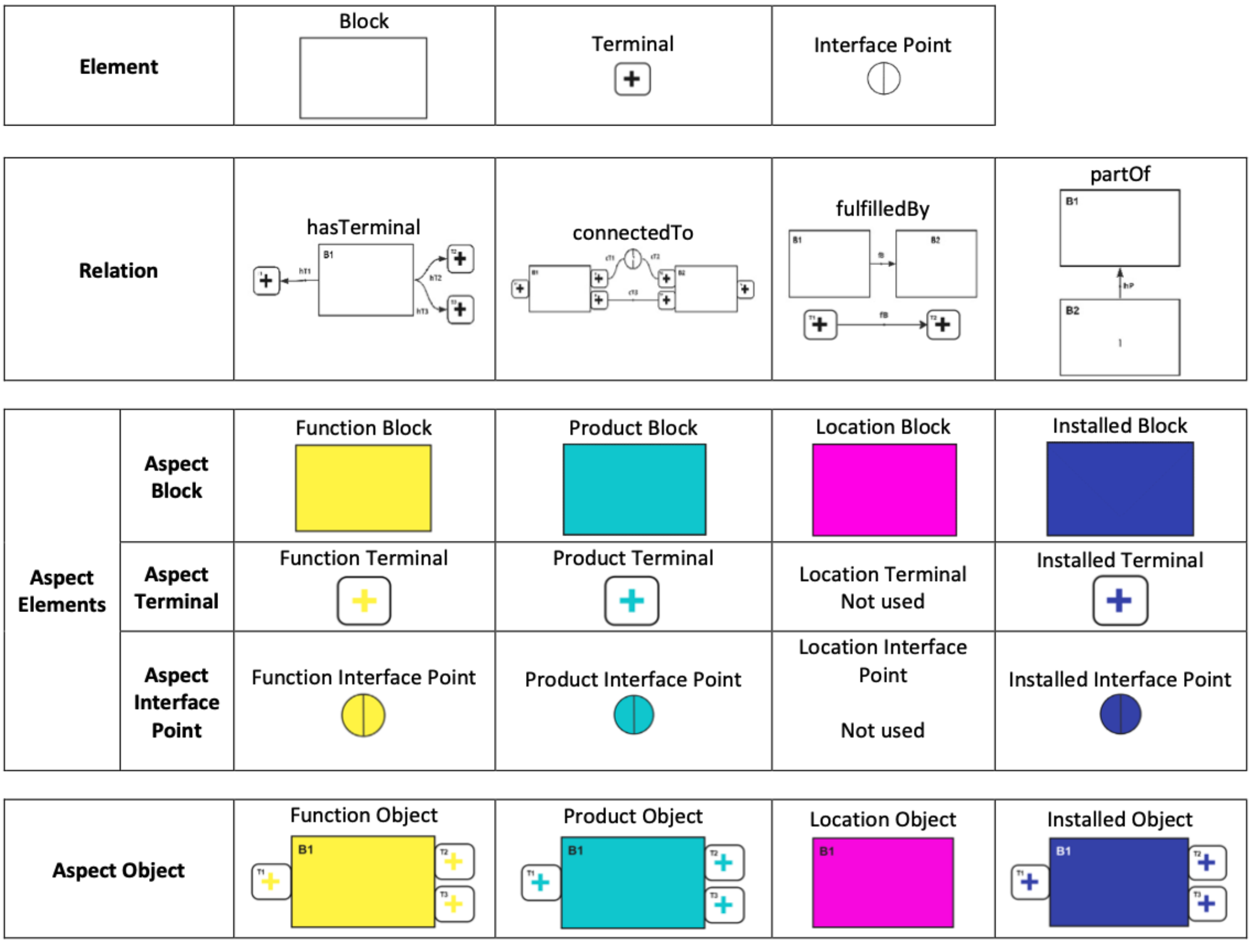


Figure 42: An overview of terms and Symbols in IMF language

Aspect Elements

Aspect Elements are blocks and terminals with exactly one aspect, as listed in Table 6.

Table 6: The different Aspect Elements

	Element	Block (B)	Terminal (T)
Function (F)	Function Element	Function Block (FB)	Function Terminal (FT)
Product (P)	Product Element	Product Block (PB)	Product Terminal (PT)
Location (L)	Location Element	Location Block (LB)	Location Terminal (LT)
Installed (I)	Installed Element	Installed Block (IB)	Installed Terminal (IT)

Relations

Relations in IMF are binary: they connect two aspect elements. Table 7 and Table 8 list all relations with their domain, range and cardinality.

Table 7: Summary of partOf and connectTo relations

Relation	Domain	Range	Cardinality
partOf	Block/Terminal	Block/Terminal	Many – 1
connectedTo	Terminal	Terminal	1 – 1

Table 8: Inter-aspect relations, their domain, range, and cardinality

Relation	Domain	Range	Cardinality
asProduct	FunctionElement	ProductElement	1 – many
asProduct	InstalledElement	ProductElement	1 – 1
asFunction	ProductElement	FunctionElement	1 – many
asLocation	ProductElement	LocationElement	1 – 1
asInstalled	ProductElement	InstalledElement	1 – many

Visualisation

A Block is visualised as a box, possibly with a collection of attributes written inside. A Terminal is visualised as a small box with a plus (+) sign, as shown in Figure 43.

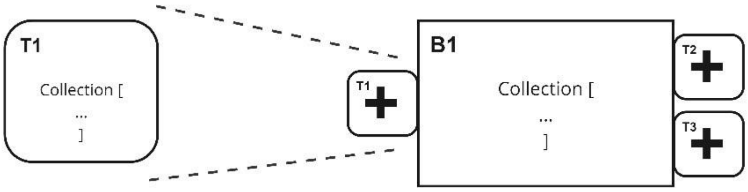


Figure 43: A Terminal

A partOf relationship partOf(B2, B1) is illustrated with an arrow pointing from the top of B2 to the bottom of B1, see Figure 44.

A connectedTo relationship is visualised as line between the Terminals it connects, as illustrated in Figure 45 which also illustrates a connectedTo relationship with an associated

Association Point as a split circle placed in the middle of the line between the connected Terminals. This is not further used in the current version of this manual.

In an IMF model the connectedTo and partOf relation are constrained so that they only relate blocks associated with the same aspect.

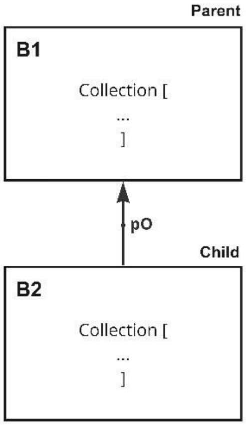


Figure 44: A partOf relationship between Blocks

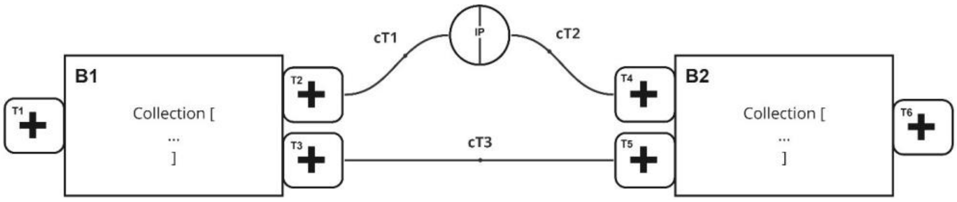


Figure 45: Two connectedTo relationships

Block

Block is the basic building block of the IMF language. A Block represents something of interest to the SME by setting the boundaries of anything which is convenient to treat as an entity. This could be a whole industry plant, a pump system, or a small location of interest.

Table 9 summarises the informal interpretation of blocks in each of the reserved aspects.

Table 9: Aspect Blocks and their intuition.

Name	**Intuition**
Function Block (**FB**)	A Function Block holds the requirements to an intended activity. Product Block (**PB**)
Location Block (**LB**)	A Location Block holds the specification of the spatial extension of an intended artefact.
Installed Block (IB)	An Installed Block holds the documentation of an actually installed artefact.

Terminal

A Terminal represents a channel of communication for a Block; hence a Terminal cannot exist without a Block. A Block may have any number of Terminals that each represents a different communication channel or port with which the Block may receive input and/or give output. A Terminal that is specified to only receive input is called an *input* Terminal. A Terminal that is specified to only give output is called an *output* Terminal. A Terminal that may both receive input and give output is called a *bidirectional* Terminal, or, simply, a Terminal. The informal interpretation of terminals in each of the reserved aspects are summarized in Table 10.

Table 10: Aspect Terminals and their intuition.

Name	**Intuition**
Function Terminal (**FT**)	Requirements to one input/output stream state of a intended activity Product Terminal (**PT**)
artefact Location Terminal (**LT**)	Not used
Installed Terminal (**IT**)	Documentation of an actually installed artefact terminal.
Function Terminal (**FT**)	Requirements to one input/output stream state of a intended activity Product Terminal (**PT**)

hasTerminal

Table 11 summarises the informal interpretation of hasTerminal relationships in each of the reserved aspects.

Table 11: hasTerminal relations and their intuition

Name	**Intuition**
hasTerminal(**FB**,**FT**)	The media state of Function Terminal **FT** is the input/output of the intended activity in Function Block **FB**
hasTerminal(**PB**,**PT**)	The Product Terminal **PT** is a specification of one input/output terminal of the intended artefact of Product Block **PB**
hasTerminal(**LB**,**LT**)	Not used
hasTerminal(**IB**,**IT**)	The actually installed terminal **IT** holds documentation of an actually installed artefact terminal **IB**

partOf

The partOf relation promotes a System-Of-Systems way of thinking. The informal interpretation of partOf relationships in each of the reserved aspects is summarized in Table 12.

Table 12: partOf relations and their intuition.

Name	**Intuition**
partOf(**FB1**,**FB2**)	The intended activity of Function Block **FB1** is a sub-activity of that of Function Block **FB2**
partOf(**PB1**,**PB2**)	The intended artefact of Product Block **PB1** is a sub-assembly of the intended artefac Product Block **PB2**
partOf(**LB1**,**LB2**)	The intended location of Location Block **LB1** is located in the intended location of Locat Block **LB2**
partOf(**IB1**,**IB2**)	The actually installed artefact of Installed Block **IB1** is sub-assembly of the actually installed artefact of Installed Block **IB2**

connectedTo

The informal interpretation of connectedTo relationships in each of the reserved aspects is summarized in Table 13.

Table 13: connectedTo relations and their intuition.

Name	Intuition
connectedTo(**FT1**,**FT2**)	The media state of Function Terminal **FT1** is equal to that of Function Terminal **FT2**.
connectedTo(**PT1**,**PT2**)	The Product Terminal **PT1** is physically connected to the Product Terminal
PT2 via some media.	Not used
connectedTo(**LT1**,**LT2**)	
connectedTo(**IT1**,**IT2**)	The Installed Terminal **IT1** is physically connected to the Installed Terminal

Appendix B: DPP data structure for the three pilots

Italian Pilot

Raw Materials		**Re-qualification procedure**	**Production procedure**
Expired prepreg in form of rolls	Prepreg waste pieces (arise from the cutting phase)	Properties: - Thermal properties (T_g) - Rheological properties (Viscosity vs temperature) ** To be modified after the tests in the pilot. Maybe more properties will be added.	Component production date
Dimension of the roll	Geometry of prepreg pieces	New process window for the material: - Temperature - Pressure of polymerization - Time	Production method: - Times - Temperatures - Pressure
Supplier of raw materials		Re-qualification date	Quality inspection results: - Visual inspection - Void content - Thickness measurements
Quantity		New expiry date (for the production procedure)	
Technical Datasheet (regarding the prepreg) - Technical properties			
History of source materials: - Production date of the source material - Expiry date of the source material - Storage conditions			

Greek Pilot

Molasses Product Passport

A QR code will be placed in the product packaging bag, which when scanned will redirect the consumer to a website. The website will look like Figure below.

The user will be able to select any of the four different components and will be redirected to the specific topic. The content of each topic is displayed below. Moreover, the user may select the ASPIS logo and be redirected to the official site of the company.

Product description:

ASPIS SA, with many years of experience in food production and guided by the utilization of high-quality raw materials of Greek origin, sustainability and the circular economy, has proceeded to the production of feed products.

Our feed is produced from the processing of citrus peels and pulp with different processes, covering the needs of our customers.

Recognizing the importance and linking the production of safe feed with the production of safe food, we provide feed products of high energy and nutritional value.

Derived from the citrus processing by-products, feed grade molasses is among the most popular molasses-based animal feed sold worldwide. Easy handling and high palatability make it an ideal animal-feed solution.

Molasses is to be stored in original containers or in on-site molasses specific tanks. Molasses should be stored out of direct sunlight, at less than 20°C and avoid contact with water. If stored in the correct manner, molasses will have a shelf life of 12 months from manufacture date, unless otherwise stated.

Molasses production adopts all the relevant standard procedures and undergoes a process of Quality Assurance to render the product fit for animal-feed production.

Lot No.:

Nutritional Analysis:

Component	Concentration (g/kg molasses)	Dry Matter Basis
Calcium		
Nitrogen		
Magnesium		
Phosphorous		
Potassium		
Sodium		
Soluble Sugars (NSC)		
Sulphur		
Dry Matter		
Cobalt		
Copper		
Iron		
Manganese		
Zinc		
pH		

Specifications

Physical & Chemical Specifications	
Polarization value (% Sucrose)	
Ash (%)	
Colour (IU)	
Moisture (%)	
Particles size	
Viscosity	
Brix	
Microbiological Specifications	

Aerobic Plate Count	Absent

Environmental Impact (LCA):

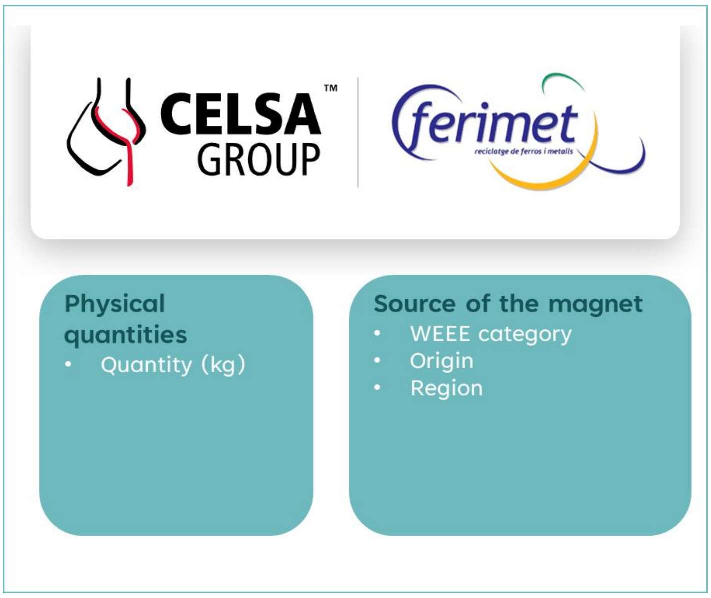
LCA analysis was carried out in accordance with the Standard ISO 14001.

Studied Category	Value (per kg of molasses)
Climate change, default, excl biogenic carbon [kg CO_2 eq.]	

Spanish pilot

Ferimet DPP

DPP per batch of magnets.



PARAMETERS	**Information/ units (S.I.)**
WEEE category	From the 6 general categories defined by the EU. Currently: • Large equipment, small equipment and/or Small IT telecommunications equipment.
Origin of the magnet	Original device from which the magnet was extracted (home appliance, washing machine, microwave, electronics or other type of WEEE)
Region of the WEEE	Code of the region where the WEEE waste comes from (es, it, fr, …)

IMDEA DPP

Physical quantities
- Quantity (kg)

Source of the magnet
- WEEE category
- Origin
- Region

Material Safety Data Sheet
- See table

Data Sheet
- See table

Sustainability data
- See table

Where: Physical quantities and source of the magnet come from Ferimet, the other blocks contain information generated by IMDEA, which are detailed in the following tables.

Material Safety Data Sheet	
PARAMETERS	UNITS (S.I.)/ Text
Material Name	
Polymer Base	%wt
Magnetic Powder	%wt
Magnetic Properties	
• Br	T
• Hc	kA/m
• BHmax	kJ/m³
Material density	kg/m³
Maximum Temperature	°C
Personal Protective Equipment	EPIs (Safety needs)
Temperature to Decompose	°C

Data Sheet	
PARAMETERS	UNITS (S.I.)
Required drying time	s
Pre-drying Temperature	°C
Maximum Temperature	°C
Temperature to Decompose	°C
Temperatures for each injection zones	°C
Temperatures nozzle	°C
Required time for each injection zone	s

Required time wait before open the mold	s

IMDEA sustainability data – other data	
PARAMETERS	UNITS (S.I.)/ text
% wt of recycled material	%wt
Quantity	Kg

IMA DPP

Sustainability data	
PARAMETERS	UNITS (S.I.)/ text
Informative message	"In order to improve the sustainability of the magnets, IMA is using magnetic material recovered from different EOL WEE. In this magnet contains magnetic materials from different recycled sources."
% wt of recycled material	%wt
Source of the magnet	*from Ferimet's DPP*
Information to recycle If possible	

Material certificate	
PARAMETERS	UNITS (S.I.) or text
Dimensional values	Mm/ª/ .. drawing specifications
weight	g
Magnetic properties	
• Gauss	kG
• Flux	(μVs·cm)
• Sample Volum	Mm^3
• Magnetic properties with temperature loss	Comparing flux or Gauss values. Tmax (ºC) and %loss
Material control	
• Br - remanence	T
• HcB - coercitivity	kA/m
• BJmax – maximum energy product	kJ/m^3
Magnetic Force	N
Coating thickness	μm
Coating composition	Data values from equipment (%wt stimated)