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WP2 – Design: AIDEAS Framework Design

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ABSTRACT	This task will be devoted to the design of the AIDEAS framework to support the entire life cycle of industrial equipment as a strategic instrument to improve the sustainability, agility and resilience of the machinery manufacturing companies. To this end, the conceptualisation of the AIDEAS Reference Architecture (RA) will follow the ISO/IEC/IEEE 42010 "Systems and software engineering – Architecture" standard, starting from a deep understanding and alignment among the most common reference architectures in the manufacturing domain, such as IIRA (mainly), RAMI4.0, IDSA, and IMSA. This task will be performed in parallel with those of its viewpoints, offering a framework that will iteratively address the architectural issues that may arise during its conception.		

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ABBREVIATIONS/ACRONYMS

AAS	Asset Administration Shell
AC	Adaptive Controller
AD	Anomaly Detector
AF	Architecture Framework
AI	Artificial Intelligence
ANSI	American National Standards Institute
API	Application Programming Interface
AQ	Autonomous Quality
AT	Austria
BDA	Big Data Analytics
BoM	Bill of Materials
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CE	Condition Evaluator
CECIMO	European Association of Machine Tools Industry
CEP	Complex Event Processing
CER	Complex Event Recognition
CFD	Computational Fluid Dynamics
CM	Conceptual Model
CNC	Computerised Numerical Control
CPES	Cyber-Physical and Embedded Systems
CPQ	Continuous Process Qualification

CPS	Cyber-Physical Systems
CPU	Central Processing Unit
CREMA	Cloud-based Rapid Elastic Manufacturing
CRM	Customer relationship management
CSV	Comma Separated Values
DB	DataBase
DCS	Distributive Control System
DIH	Digital Innovation Hub
DIS	Disassembler
DO	Delivery Optimiser
DPP	Digital Product Passport
DSS	Decision Support System
DoES	Design of Experiments
EC	European Commission
EIP	Enterprise Integration Paterns
EU	European Union
ERP	Enterprise Resource Planning
ES	Spain
ESB	Enterprise Service Bus
FCS	Field Bus Control System
FO	Fabrication Optimiser
GDI	Green Deal Index
GPU	Graphics processing unit
GR	Greece
HMI	Human-Machine Interfaces

HMM	Hidden Markov Models
HRI	Human Robot Interaction
HSM	Hardware Security Module
HTTP	Hypertext Transfer Protocol
ID	Identification
IdP	Identity Provider
IDS	International Data Space
IDSA	International Data Space Association
IDS-RAM	International Data Space Reference Architecture Model
IEC	International Electrotechnical Commission
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IIRA	Industrial Internet Reference Architecture
IIS	Industrial Internet System
IMSA	Intelligent Manufacturing System Architecture
IMT	Intelligent Machine Tool
IoT	Internet of Things
IP	Internet Protocol
IPSO	IP Smart Object
ISO	International Organisation for Standardisation
IT	Information Technology
ITI	Information Technology Institute
JJWT	Java Web Token
JSON	JavaScript Object Notation
JWT	JSON Web Token

LC	Life Cycle
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
S-LCA	Social Life Cycle Assessment
LfD	Learning from Demonstration
M2C	Machine-to-Machine
MC	Machine Calibrator
MDG	Machine Synthetic Data Generator
MDO	Machine Design Optimiser
MES	Manufacturing Execution System
ML	Machine Learning
MP	Machine Passport
MRP	Material Requierement Planning
NDI	Non-Destructive Inspection
OEM	Original Equipment Manufacturer
OPC	Open Platform Communications
OPC-UA	Open Platform Communications – Unified Architecture
OT	Operational Technology
PDU	Protocol Data Unit
PL	Poland
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
PM	Prescriptive Maintenance
PO	Procurement Optimization
QA	Quality Assurance

QR code	Quick Reference code
Q-RA	QU4LITY Reference Architecture
R&D	Research and Development
RA	Reference Architecture
RAF	Reference Architecture Framework
RAMI4.0	Reference Architectural Model Industry 4.0
REST	Representational State Transfer
RF	Reference Framework
RL	Readiness Level
RM	Reference Model
RIDS	Reliable Industrial Data Service
ROS	Robot Operating System
SCADA	Supervisory Control And Data Acquisition
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SDE	Simple Derived Event
SDK	Software Development Kit
SMEs	Small and Medium-sized Enterprises
SOA	Service Oriented Architecture
SoS	Systems of Systems
SQL	Structured Query Language
SR	Smart Retrofitter
SSL	Secure Sockets Layer
SW	Software
TPM	Trusted Platform Module

TR	Turkey
UA	Unified Architecture
UI	User Interface
vf-OAK	Virtual Factory Open Applications Development Kit
Vf-OS	Virtual Factory Operating System
WLAN	Wireless Local Area Network
WP	Work Package
WSN	Wireless Sensor Network
XML	Extensible Markup Language
ZDM	Zero Defects Manufacturing
ZDMP	Zero Defects Manufacturing Platform
ZDZW	Zero Defects Zero Waste

Executive summary

The objective of AIDEAS will be to develop AI technologies that support the complete lifecycle of industrial equipment, encompassing design, manufacturing, use, and repair/reuse/recycle processes. The primary objective is to enhance European machinery manufacturing companies' sustainability, agility, and resilience. AIDEAS will deploy 4 integrated Suites:

1. **Design**: Incorporates AI technologies that seamlessly integrate with CAD/CAM/CAE systems to optimize the design of structural components, mechanisms, and control elements of industrial equipment.
2. **Manufacturing**: Focuses on leveraging AI technologies to improve various aspects of industrial equipment production. This includes efficient selection and procurement of purchased components, optimization of manufacturing processes for parts, sequencing of operations, quality control measures, and customization capabilities.
3. **Use**: Centres around AI technologies that offer added value to industrial equipment users. These technologies provide enhanced support for installation, initial calibration, production processes, quality assurance, and predictive maintenance, ensuring optimal operating conditions.
4. **Repair-Reuse-Recycle:** Utilizes AI technologies to extend the useful lifespan of machines through prescriptive maintenance (repair), enable smart retrofitting for a second life (reuse), and identify the most sustainable end-of-life approaches (recycle).

One of the challenges in implementing the different solutions developed to support the whole life cycle (design, manufacturing, use and repair/reuse/recycling) is the development of the AIDEAS Reference Architecture (AIDEAS RA) for all industrial equipment as a strategic tool using innovative and sector specific technologies as a basis.

This document provides the first version of the AIDEAS RA, which represents the first deliverable of Task 2.1. T2.1 "Reference Architecture & Viewpoints v1" is dedicated to the design of an architecture for the development of solutions considering the following differentials. This reference architecture will use for the development of the AIDEAS solutions and will not be designed from scratch. For this, a series of previous research will be carried out considering different relevant initiatives. At this point, the different partners of the Consortium will provide their previously acquired knowledge on the subject and represent a solid base on which to transfer this knowledge. Also, this document deepens state of the art and presents an analysis of the most recent versions of some standard reference architectures relevant to digital industries; it is also supported by a contextualization of the problem to be addressed to align the architecture with the needs and requirements of the life cycle of industrial equipment. Different European projects were defined and analyzed with the intention of gaining more knowledge of the current state of the art of the different reference architectures used in other projects. As a result, the desired knowledge was obtained to develop the AIDEAS reference architecture. Starting from the supply chain infrastructure to understand the need for the creation of the machine port and linking it with a traditional 4-tier architecture divided into functional domains. Regarding to viewpoints, the different stakeholders that can interact with the solutions are analyzed and linked with the defined roles and their relationship with the data flow of a company. Finally, the use of the solutions, their functionality and the definition of technologies and needs for their implementation are analyzed. In addition, an online web site has been created where relevant information about the different viewpoints can be viewed in greater depth.

Document structure

Section 1 Methodology: In this section the concept of Reference Architecture will be presented, according to different standards. For this, the conceptualization of the AIDEAS Reference Architecture (RA) will follow the ISO/IEC/IEEE 42010 "Systems and software engineering - Architecture" standard. In addition, the process to be followed to complete this deliverable will be defined.

Section 2 Background and Vision: The context of this deliverable will be established, placing it in the industrial sector and focusing on the framework that supports the entire life cycle of industrial equipment as a strategic tool to improve the sustainability, agility, and resilience of machinery manufacturing companies. This state of the art will include relevant ongoing and finalized initiatives and solutions at the European level that address the already defined framework.

Section 3 Digital Passport: In this part of the paper, we will analyse the concept of the digital passport as a point of inspiration for the creation of the Machine Passport.

Section 4 Context of AIDEAS: The project context is a section that provides essential information about the environment in which the project will be developed. It presents the key elements that help to understand the current situation and the factors affecting the project. Essential information on the problem or need to be addressed, the justification of the project, its scope, constraints and assumptions, the industrial context, the analysis of the environment and the framework of the industrial ecosystem are collected. This information helps to consolidate the project and its objectives for its correct planning and execution.

Section 5 AIDEAS Reference Architecture: Preliminary version of the AIDEAS Reference Architecture (AIDEAS RA).

Section 6 Conclusions and Next Steps: Activities planned for the next periods, input and output to define the final version for the AIDEAS RF.

1. Methodology

The conceptualization of a system's architecture, as defined by the ISO/IEC/IEEE 42010 "Systems and software engineering - Architecture" standard, plays a crucial role in understanding the fundamental aspects and key characteristics of the system, including its behavior and composition [13]. It outlines the system's structure, encompassing its entities and the interactions between each entity and its environment. RAs serve as general guidelines that abstract the specific requirements and technologies of different implementations and use cases. They provide the following benefits:

- Common lexicon that facilitates communication: RAs establish a shared vocabulary that facilitates effective communication among stakeholders.
- Common (architectural) vision: RAs help focus and align the efforts of multiple individuals and teams involved in the system's development.
- Modularisation: RAs support dividing the development effort into manageable modules and ensuring seamless integration in later stages.
- Guidance and baselines: RAs offer guidance and serve as baseline references to ensure consistency and best practices.
- Articulation of domain and realization concepts: RAs articulate the concepts specific to the system's domain and its realization, providing a comprehensive understanding.

This document introduces the Reference Architecture of AIDEAS Solutions, which employs a multi-view approach. By utilizing multiple views, the distinct concerns of the various stakeholders involved in the AIDEAS project, including technical partners and business partners, can be addressed separately. This approach facilitates the individual handling of functional and non-functional requirements. The design of the **AIDEAS Reference Architecture (AIDEAS RA)** will be accomplished through an architecture-centric, scenario-driven, iterative development process.

In the methodology of this project, a crucial section called "Context of AIDEAS" has been included. This section has been developed with the aim of providing a detailed and solid understanding of the environment in which the project will be carried out. In it, a comprehensive description of the problem or need that the project seeks to address has been provided, as well as a clear justification of its relevance and benefits. In addition, the scope of the project has been established, defining the limits and constraints to be considered. The constraints and assumptions that may influence the implementation of the project have also been considered, as well as the organizational context and the analysis of the environment in which the project will take place. In summary, the project context section of the methodology provides a solid and comprehensive basis for the successful development and implementation of the project, ensuring that the full picture in which the project will operate is considered.

Following the terminology defined in the ISO/IEC/IEEE 42010 [13], the term "architecture" denotes the core ideas or characteristics of an entity. An Architecture Framework (AF) is a set of standards, guidelines, and procedures for describing architectures that have been created within a particular application domain or group of Stakeholders. This AF contains several Architecture Viewpoints; hence, it considers a set of conventions for the creation, interpretation, and use of an architecture view that frames one or more concerns held by the system´s Stakeholders. The AF can contain a Correspondence Rule that identifies or names relationships between two or more architectural description elements. To this end, a model kind is a category of model distinguished by its key characteristics and modelling conventions.

The following Figure 1 presents a graphical representation of the mentioned entities and their interrelationships.

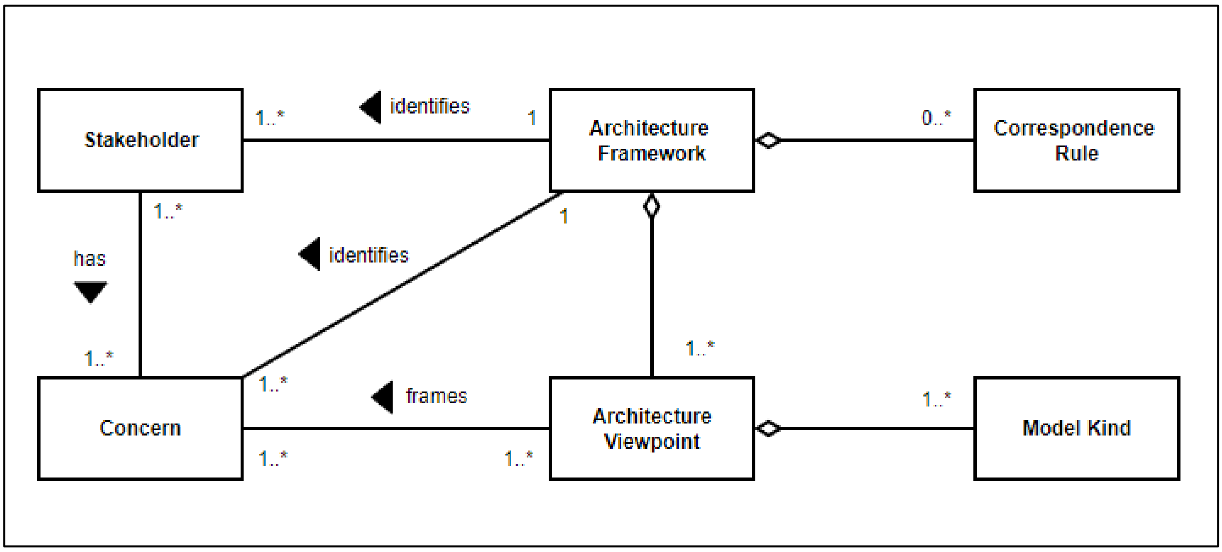

Figure 1. The Architecture Framework entity model in ISO/IEC/IEEE 42010.

In the context of the AIDEAS AF (further described in Sections **Error! Reference source not found.** and 5), the most relevant viewpoints specified are the following: Business View, Usage View, Functional View, and Implementation View. Throughout the development of the reference architecture for the AIDEAS project, it will apply the methodological approach seen above.

Finally, in order to reduce the size of this deliverable and to provide an interactive and updatable tool throughout the project that can be used as a reference document by all developers, a documentation website has been implemented in the URL: https://viewpoints.aideas-srv.cigip.upv.es/

2. Background and Vision

2.1 Project Background

Over the Industrial Revolution, industrial equipment has been considered a key enabler for industrial development. EU has a historically strategic position in this sector: the European Association of the Machine Tool Industries (CECIMO), composed of 15 National Associations of machine tool builders, represents approximately 1.300 industrial enterprises in Europe (EU + EFTA + Turkey), over 80% of which are SMEs, and covers 98% of total Machine Tool production in Europe and about 36% worldwide (CECIMO, 2023). Despite the outbreak of the COVID-19 pandemic, CECIMO's machine tool exports during Q4 2020 are valued at €4.36 billion[1]. In a highly globalised world, and with the appearance of new actors in play, it is critical for the EU to keep researching disruptive ways to upgrade its ecosystem to maintain its position as the world's largest producer and exporter of machine tools.

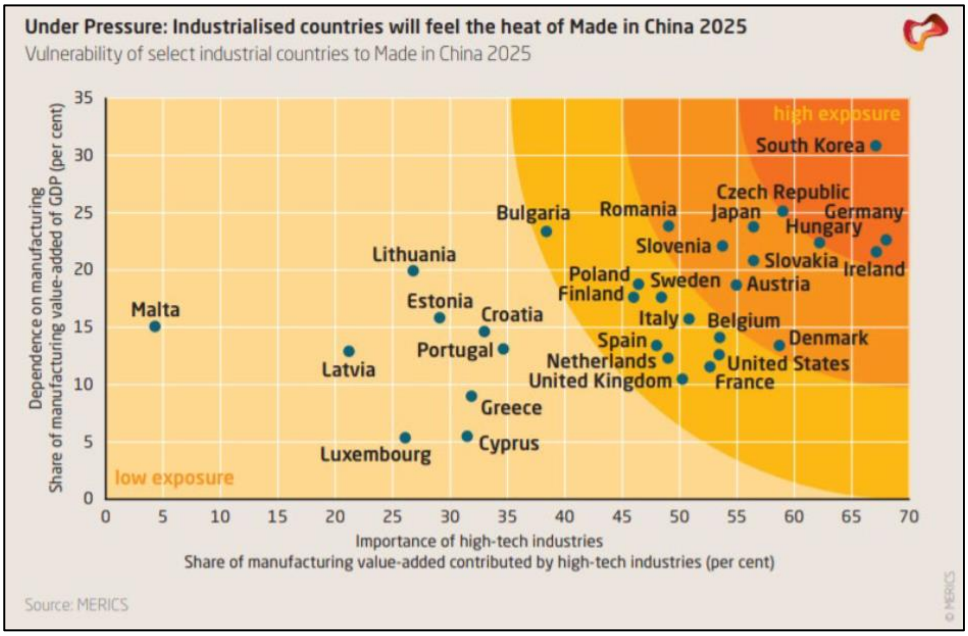

Figure 2. Vulnerability of selected industrial countries to Made in China [29].

The machinery industry in Europe is a basis for employment, growth and wealth, with reports that state that around 2.9 million people are employed in Europe under the mechanical engineering sector[2].

However, it lives from a technological edge that is being feverously challenged. The astonishing growth of China during the 21st century positioned itself in direct competition with the EU. A few years ago, China's manufacturing was considered a step below in terms of precision and overall quality, placing the EU in a competitive advantage in the industrial equipment sector.

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[1] https://vdw.de/wp-content/uploads/2021/07/pub_vdw-marktbericht_2020_2021-06-14_web.pdf

[2] How to succeed Strategic options for European machinery.ashx (mckinsey.com)

The Chinese authorities have therefore addressed this problem with strategic plans such as "Made in China 2025" [3] to modernise its industrial capabilities. The USA has already shown its concern of how this plan could "significantly alter the domestic and global competitive landscape in targeted sectors". As a clear example of how the Asian superpower could disrupt the EU's dominant position in the industrial equipment sector, the Chinese Ministry of Science and Technology is devoting a budget for the further development of the so-called Intelligent Machine Tool (IMT) with the help of the new generation of AI technologies (Chen et al., 2019).

Due to the current status quo, the EU is anticipated to adopt a proactive rather than a reactive stance to maintain its industrial equipment sector as a cutting-edge arena and preserve its dominant market position. Ensuring the success of this endeavour is vital, requiring the provision of digital technologies to all stakeholders within the Union. These technologies will guarantee resilient design, deployment, and reuse of industrial equipment, enhancing global competitiveness and strengthening the EU's industrial and strategic autonomy. This commitment aligns with the objectives outlined in the EU's New Industrial Strategy communication[4]. Moreover, since industrial equipment is one of the main responsible for the efficiency of manufacturing, the implementation of AI technologies in this sector would provide not only increased efficiency and optimal use of energy in the equipment itself but also in all industrial processes that are dependent on its output, which would be strategical towards EU's priority on sustainable development and circular economy towards its transition to climate neutrality.

2.2 State of the art in Industrial Equipment Product Life Cycle Boosting Agility, Sustainability and Resilience

The state-of-the-art in Industrial Equipment Product Life Cycle Boosting Agility, Sustainability and Resilience involves the use of AI-based technologies throughout the entire life cycle of the equipment. This includes the use of artificial intelligence (AI) in the design and development phase, to optimize the performance and efficiency of the equipment.

In the operation and maintenance phase, AI-based tools are used for predictive maintenance, condition monitoring, and real-time monitoring of equipment performance. Additionally, AI-based algorithms are used for optimizing the supply chain and logistics, to minimize downtime and increase the overall resilience of the equipment.

Furthermore, AI-based tools are used for recycling and disposal of the equipment, to minimize environmental impact and improve sustainability. Overall, the integration of AI-based technologies throughout the life cycle of industrial equipment is crucial for dealing with competitive pressures and enhancing the performance and sustainability of the industry.

[3] U.S. Chamber of Commerce. (2017). Made in China 2025: Global Ambitions Built on Local Protections.
[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0102&from=EN

A significant number of initiatives from European projects have been oriented towards this theme. In order to take into account what other initiatives exist, information has been collected from different European projects in which different AIDEAS partners are involved, with the aim of understanding, understanding and sharing ideas that are currently being addressed in a collaborative way.

2.2.1 AI-PRISM

AI-PRISM[5] is a project born in October 2022 that aims to provide an ecosystem of human-centric AI-based solutions for manufacturing scenarios that are difficult to automate and require speed and versatility. The integrated and scalable ecosystem will incorporate installation-specific solutions to enable semi-automated and collaborative manufacturing within flexible production processes. Notably, the ecosystem will eliminate the need for specialized robotic programming skills by employing programming-by-demonstration modules. The ecosystem will be built upon four primary pillars:

- Human-Centered Collaborative Robotic Platform.
- Human-Robot Cooperation Ambient.
- Social Human-Agent-Robots Teams Collaboration and Open Access Network Portal.

One of the major obstacles, and a significant challenge, for the implementation of collaborative robots in the workplace, particularly for SMEs, is their programming for intricate tasks (such as artisanal craftsmanship). To overcome this barrier, AI-PRISM's robots are designed to learn complex processes by observing human operators performing them. This will provide an affordable solution for SMEs by making programming a new task a more intuitive process that does not require advanced programming skills. Similar to how a craftsman's apprentice learns by watching their master, AI-PRISM's robots will learn through observation. To evaluate the performance, transferability, scalability, and potential for large-scale deployment of these solutions, real operational environments will be utilized in four pilot projects spanning key manufacturing sectors. These sectors include Furniture (ES), Food/Beverage (GR), Built-in Appliances (TR), and Electronics (PL). Additionally, a generic demonstration facility (AT) will be employed to showcase the capabilities of the solutions.

2.2.2 CLARUS

The CLARUS[6] project aims to connect the Sustainable Paradigm in the food industry and AI-based applications, with the goal of developing a platform with high communications and processing capabilities, as well as the use of standardized open protocols and data models that will allow resource consumption assessment and traceability for food industry processes. Clarus project will target the food industry lifecycle for improving the friendliness of the European food industry with the Green Dela concepts and policies. In this regard, adopting a problem-solving approach, the CLARUS realises that the food manufacturing industry consists mainly of primary food

[5] AI-PRISM – AI-Powered Human-Centred Robot Interactions for Smart Manufacturing (aiprism.eu)
[6] https://clarus-project.eu/

production, by-products processing, and logistics and delivery. The project targets improving the European food industry's eco-friendliness through a problem-solving approach focusing on reducing water and energy consumption and plastic waste in primary food production, reducing fuel consumption, CO_2 emissions and increasing generated fuel and pet food in by-product processing, and reducing fuel consumption and CO_2 emissions in logistics and delivery.

The Digital Transformation of food companies can enable Sustainability Transformation by leveraging the advantages of smart technologies for data management and processing. While the decision to digitize food manufacturing processes is becoming increasingly clear, achieving better sustainability standards is not as straightforward. There is often confusion within industrial sectors about the actions needed for an efficient Green Transition.

To address this, the CLARUS project is closely aligned with the European Green Deal program to create a quantitative and standard methodology for developing a sustainable food industry structure and culture that can generate business while minimizing environmental impact. The project aims to not only optimize resources and logistics through pilot solutions but also to create a general contribution through the creation of a Green Deal Index (GDI).

2.2.3 TALON

TALON aims to lead the way in the upcoming Industrial revolution by developing a fully automated AI architecture that brings intelligence to the edge in a manner that is flexible, adaptable, explainable, energy-efficient, and data-efficient. The architecture of TALON is built upon three foundational pillars:

- An AI orchestrator: This component coordinates the network and service orchestrators, optimizing the relationship between edge and cloud resources. It enhances the reusability of datasets, algorithms, and models by determining the optimal placement for each component.
- Lightweight hierarchical blockchain schemes: These schemes introduce new service models and applications within a privacy and security framework. They offer protection and privacy while enabling novel service models and applications.
- Digital-twin empowered transfer learning and visualization approaches: TALON incorporates new methods for transfer learning and visualization, powered by digital twins. These approaches enhance the trustworthiness and transparency of AI systems.

TALON combines the advantages of AI, edge and cloud networking, blockchain technology, and digital twins. It utilizes new key performance indicators, a novel theoretical framework, personalized and perpetual protection mechanisms based on security, privacy, and trust, automatic co-optimization of edge and cloud resources, semantic AI for reduced learning latency and increased reusability, and digital twins for visualizing AI outputs and facilitating human-in-the-loop approaches.

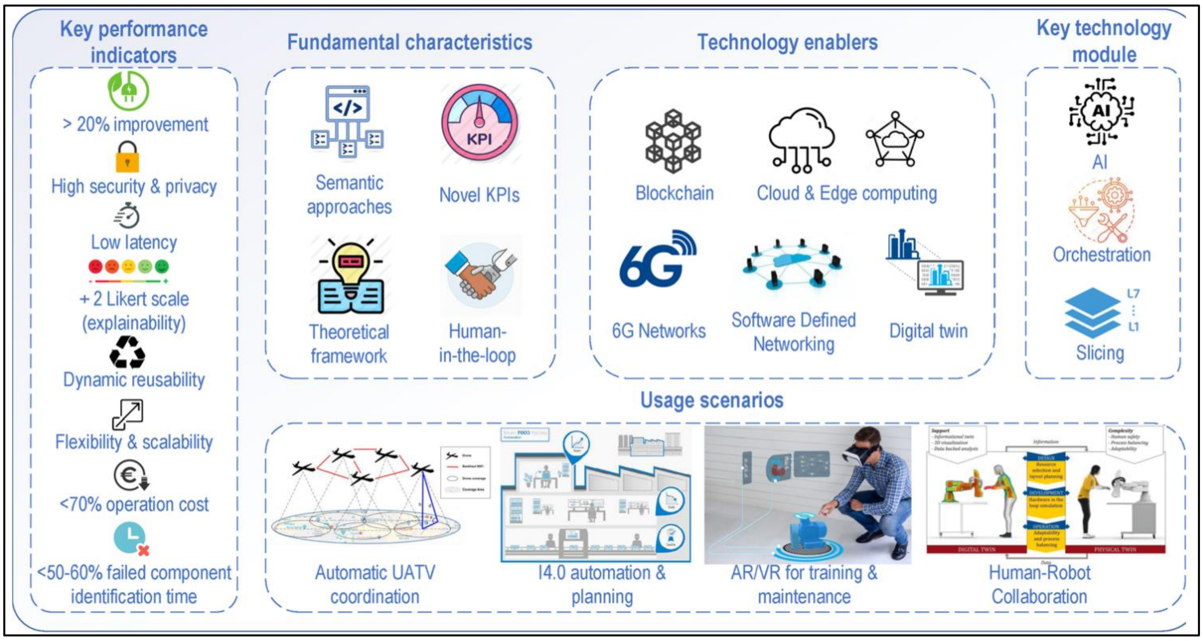


Figure 3. TALON concept.

Additionally, TALON aims to provide solutions for various industries such as manufacturing, transportation, healthcare, and more by utilizing AI architecture for applications like predictive maintenance, automation of complex tasks, and real-time decision-making. TALON's approach also seeks to address challenges related to data privacy and security by utilizing blockchain technology and digital twin solutions to ensure secure and transparent data management. Overall, TALON's goal is to enable the next industrial revolution by creating a fully automated AI architecture that brings intelligence near the edge, while also addressing the challenges of data privacy, security, and transparency in an energy and data-efficient manner.

2.2.4 AGILEHAND

The primary objective of AGILEHAND[7] is to develop advanced technologies for autonomously grading, handling, and packaging soft and deformable products. These technologies serve as strategic tools to enhance the flexibility, agility, and reconfigurability of production and logistics systems within European manufacturing companies. AGILEHAND will implement three integrated suites:

- **Smart sensing suite**. This suite incorporates self-calibrating sensing solutions that enable the grading of both interior and exterior quality of delicate objects. It will also create an integrated mesh of overlapping sensors, improving traceability, agility, and reconfigurability within the production line.
- **Self-adaptive handling, sorting and packaging suite**. This suite comprises robotic manipulation systems capable of reacting to product quality. These systems can pick up and

[7] AgileHand Project - AgileHand

reorient different soft and deformable products without causing any damage. Collaboration with human operators is facilitated through collaborative approaches.

- **Agile, flexible and rapid reconfigurable suite**. This suite consists of AI-based solutions that monitor, control, and synchronize production and logistics flows. It enables adaptive control and facilitates rapid reconfiguration to accommodate changing requirements and optimize efficiency.

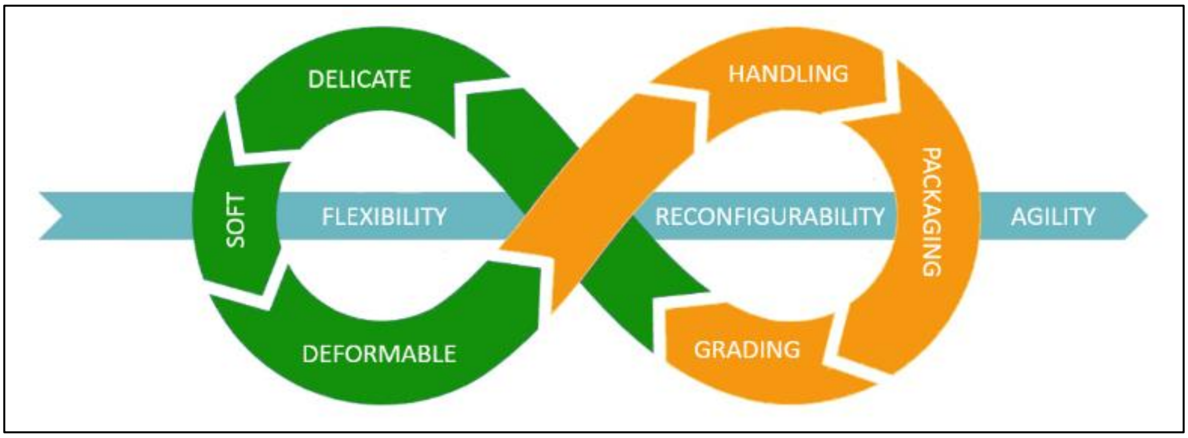


Figure 4. Agilehand model.

The AGILEHAND Solutions will be demonstrated in 4 industrial pilots that differ in characteristics of the surface, deformability, and consistency of the products to be handled.

2.2.5 C2NET

The C2NET[8] project began in October 2015 and was completed in December 2017. This Project is a cloud-enabled toolset for supporting the SMEs' supply network optimization of manufacturing and logistic assets. Plans for demand, distribution, and manufacturing are the foundation of this asset. This project provides scalable real-time software, architecture, and platforms to enable supply network partners to share or store products, logistics or process data, collaboratively compute production plans to maximize manufacturing resources, etc.

To collect data and spot patterns in real-time, C2NET is built to support the storing of information from both legacy systems and Internet of Things environments. To facilitate collaborative demand-driven optimization of the supply network of logistical and manufacturing assets, C2NET offers a range of cloud-based technologies. Real-time scalability with interoperability is one of the goals of the C2NET architecture to make this work.

[8] https://cordis.europa.eu/project/id/636909

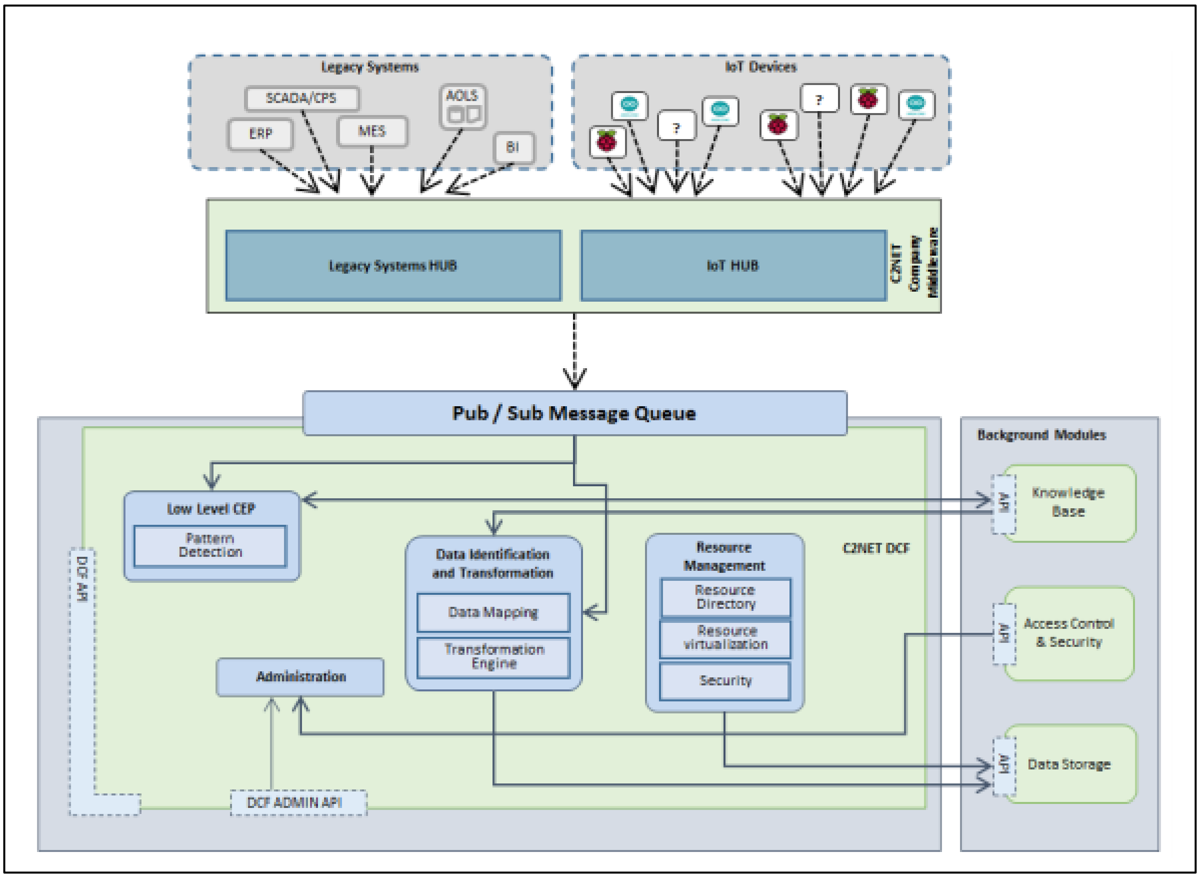


Figure 5. C2Net Architecture.

2.2.6 vf-OS

The development of vf-OS[9] (virtual factory Open Operating System) began in October 2016 and will be completed in October 2019. This project enables the use of Industry 4.0 technologies. This provides various services for various manufacturing and logistics processes, both within the organization and among the various supply providers. vf-OS employs a Service Oriented Architecture (SOA), in which various components are used to implement various individual solutions. All of the ecosystem's interconnected components publish a REST interface for data exchange, which is also used by the project's messaging bus.

vf-OS is described as an Open Operating System for Virtual Factories (see Figure 6), deployed in a cloud platform. This platform offers services to integrate into manufacturing and logistics processes, as an application marketplace containing many features.

[9] Virtual Factory Open Operating System | vf-OS Project | Fact Sheet | H2020 | CORDIS | European Commission (europa.eu)

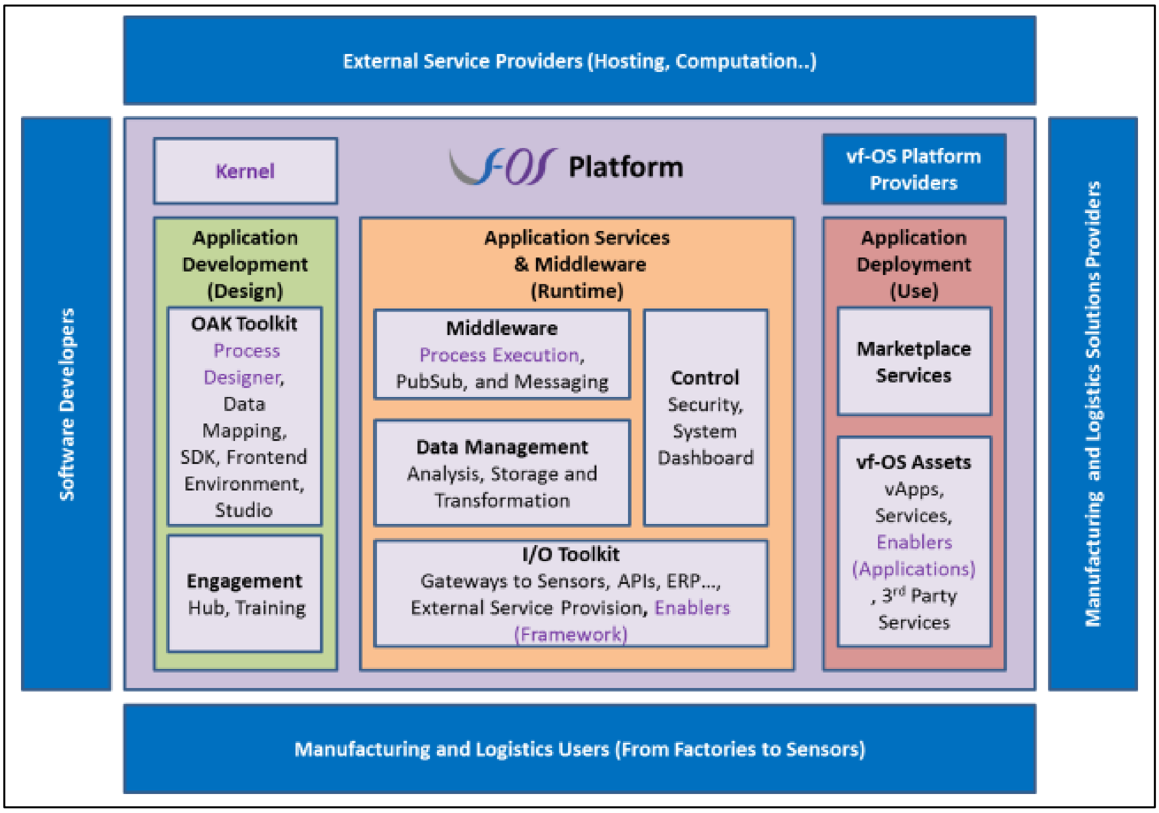


Figure 6. vf-OS Architecture.

2.2.7 DIH4CPS

The initiative to promote DIHs for the integration of interoperability in the cyber-physical systems of European SMEs (DIH4CPS[10]) was launched in January 2020 and ended in December 2022. The aim was to help European companies overcome the obstacles to innovation and to position Europe as a world leader in the industry. DIH4CPS therefore created an interdisciplinary network of DIHs and solution providers, focused on cyber-physical and embedded systems, which will interweave knowledge and technologies from different fields and connect regional clusters with the pan-European group of DIH experts.

The DIH4CPS Network is a sustainable network, instantiated within the I-VLab organization, which will remain active well beyond the duration of the DIH4CPS project. It develops a customized business model, combined with professional operational and sustainability support, to ensure smooth integration and thus the overall sustainability of the network. DIH4CPS validated its ecosystem with 13 initial member DIHs, 12 additional DIHs after the first open call, and seven else after the second open call, providing European industry with unprecedented ease of access to world-class domain expertise in the development of CPS and smart embedded systems, and with 11 initial Application Experiments across multiple key sectors, expanded to a total of 23 after successive incorporations.

[10] DIH4CPS - DIH4CPS

2.2.8 ZDMP

The ZDMP[11] platform was designed to provide factories with a highly interoperable and expandable solution that helps them achieve the goal of zero faults. By integrating ERP and plant systems, ZDMP enhances quality and increases production benefits (7). The architecture also offers a wide range of design options.

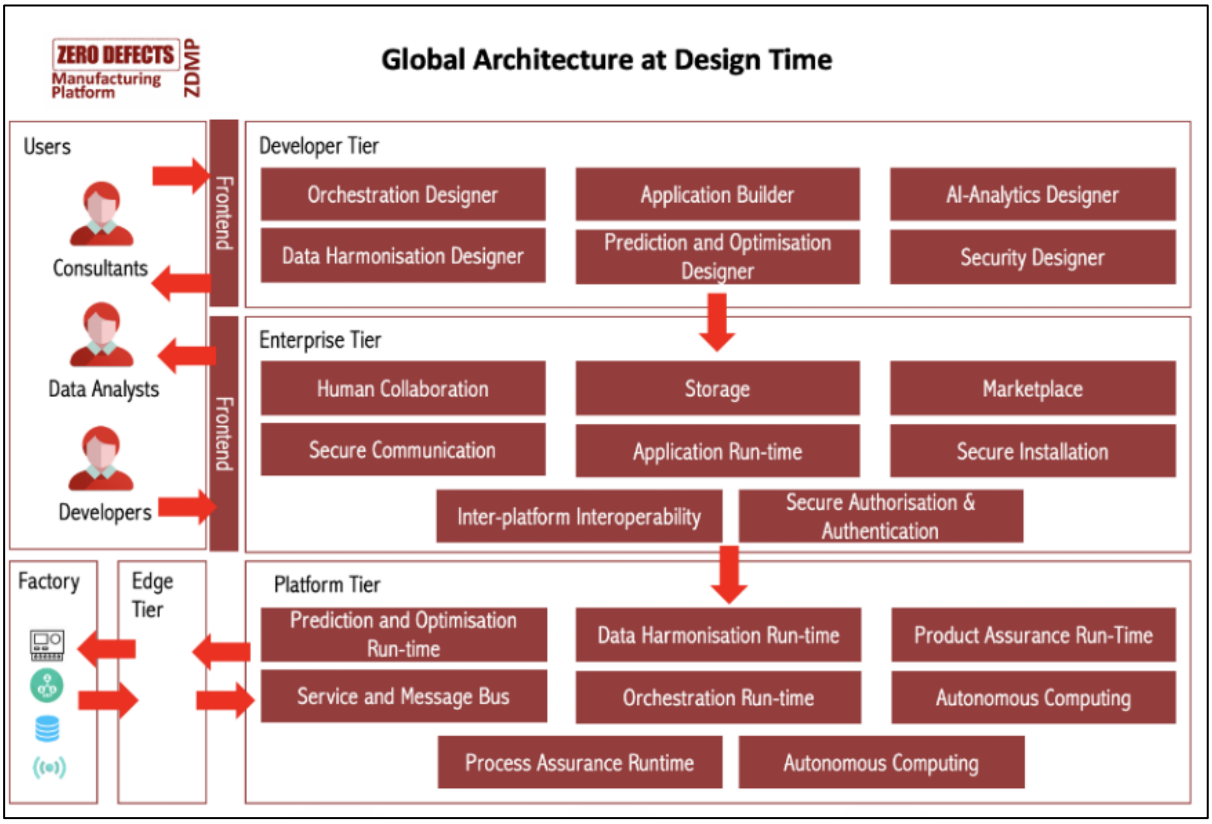


Figure 7. ZDMP Global Architecture.

ZDMP has an app store where users can find applications that meet the needs of their factory. Additionally, the ZDMP SDK (Software Development Kit) allows users or third-party companies to develop and integrate new applications into the platform. The SDK provides developers with the necessary tools to do so.

ZDMP draws on the outcomes and concepts developed in other research projects, such as Cloud-based Rapid Elastic Manufacturing (CREMA), Cloud Collaborative Manufacturing Networks (C2NET), or Virtual Factory Operating System (vf-OS), in order to ensure the quality of the production process and dedicated work streams.

[11] Zero Defect Manufacturing Platform | ZDMP Project | Fact Sheet | H2020 | CORDIS | European Commission (europa.eu)

Launched in 2019, the ZDMP activity is a 4-year project that aims to create platforms for achieving excellence in manufacturing through zero-defect processes and products. To achieve this goal, ZDMP integrates various technologies based on certain principles[12].

- **Container first.** All ZDMP components are prepared to run on Docker. This is the basis for scalability or composability in the platform.
- **Extensibility.** Every container contains an API that allows sharing or extending services on the platform. All are documented by the OpenAPI specification.
- **Distributed Architecture**. All components run in a distributed fashion. ZDMP uses both Docker Swarm and Kubernetes, which allows it to run in different ways and improves scalability.
- **Composability.** Each ZDMP component can be adapted to any specific ZDMP instance, so it adapts to any solution.
- **Secure**. Includes several security controls (Authentication, centralised authorisation, SSL communication, etc).
- **Big Data and AI-Driven**. Provides Big Data and AI tools, models and infrastructure.
- **Connectivity.** Connects to any industry protocol.
- **Developer experience**. Provides tools to be able to develop new components.
- **Extensible**. Components can be extended, and new ones can be generated.
- **Interoperable**. It can be connected to other platforms via API.

2.2.9 i4Q

The Industrial Data Services for Quality Control in Smart Manufacturing (i4Q) project, which started in January 2021 and will end in December 2023, aims to provide reliable industrial data services (RIDS) based on IoT through 22 different solutions that can manage the large amount of industrial data generated by interconnected, smart, and small factory devices. These solutions support online manufacturing monitoring and control.

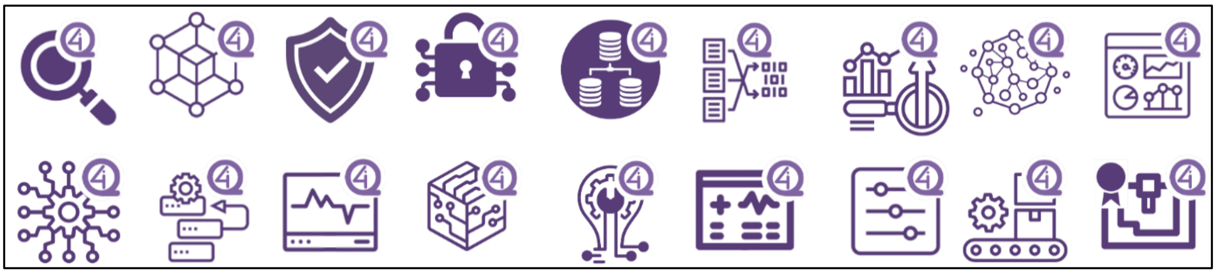


Figure 8. i4Q tools.

The i4Q framework ensures data reliability with functions organized into five core capabilities related to the data cycle: sensing, communication, IT infrastructure, storage, and analysis and optimization (**Error! Reference source not found.**). The i4Q RIDS will include simulation and optimization tools for continuous qualification of manufacturing line processes, quality diagnosis, reconfiguration, and certification to ensure high manufacturing efficiency, resulting in an integrated approach to defect-free manufacturing.

[12] Overview | ZDMP (angry-spence-1ecc9e.netlify.app)

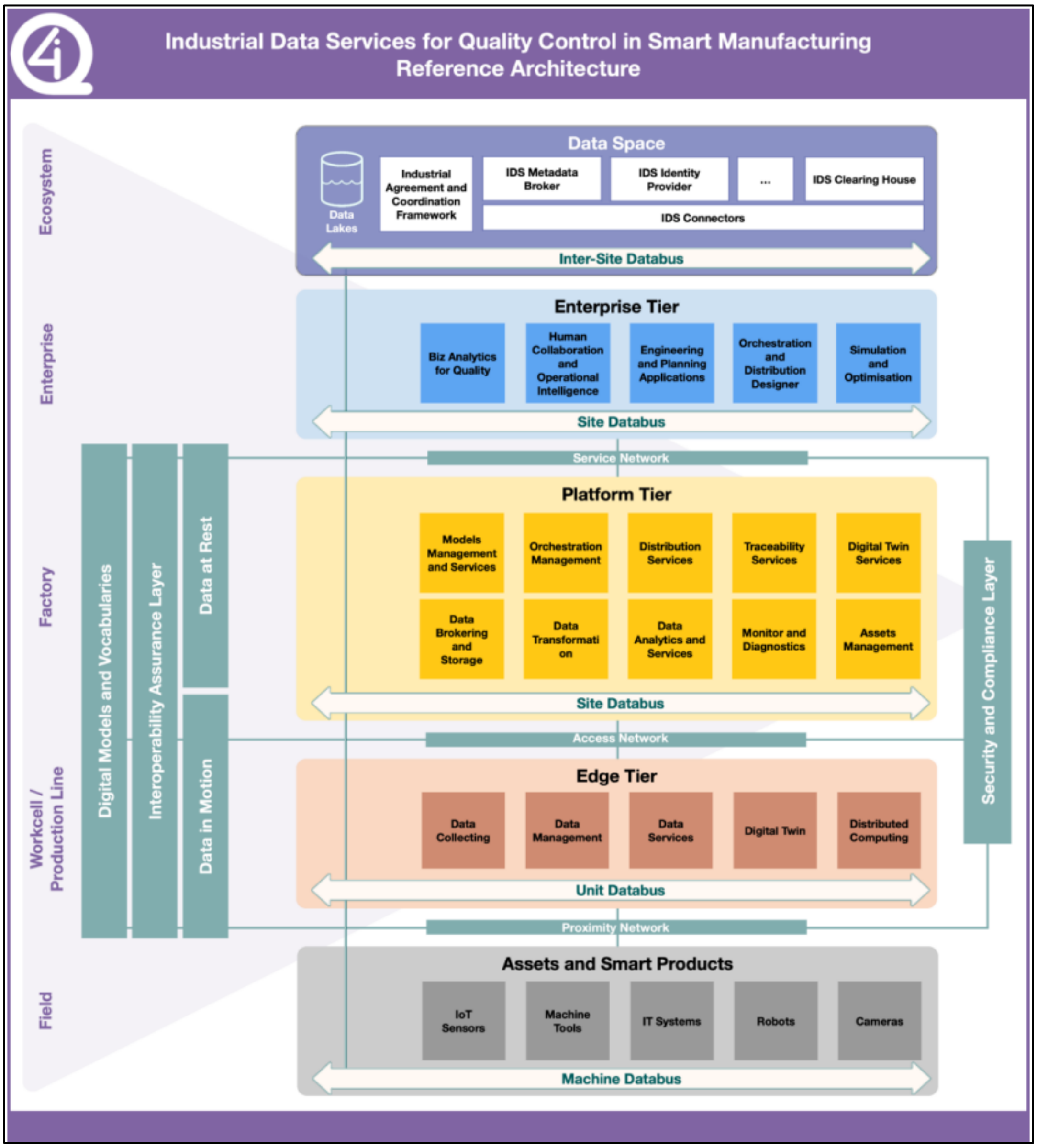


Figure 9. i4Q Architecture.

2.2.10 ZDZW

The ZDZW[13] project specializes in providing a selection of non-destructive inspection technologies that use IoT, allowing for precise evaluations of factors that impact product quality across various technical fields such as part integrity, visual requirements, and thermal process efficiency. Their inspection solutions are cost-effective and aim to improve return on investment by offering subscription and pay-per-Use Models. The main goal of ZDZW is to reduce defects and waste in manufacturing processes by focusing on three key areas: improving monitoring and control for process quality assurance, streamlining rework and repair procedures to recover necessary parts and decrease scrap, and continuously evaluating sustainability to optimize the

[13] ZDZW Project | ZDZW Project (zdzw-project.eu)

use of materials and components throughout the production line. The main goal of ZDZW is to minimize defects and waste in the manufacturing process. They achieve this by focusing on three key areas that encompass the entire manufacturing process and product lifecycle:

- Improving monitoring and control to guarantee process quality, resulting in an increased first-time manufacturing rate, as well as improved durability properties and reduced waste generation.
- Implementing digital enhancement techniques to repair procedures to recover necessary parts and decrease waste.
- Continuously assessing sustainability to optimize the utilization of materials and components throughout the production line.

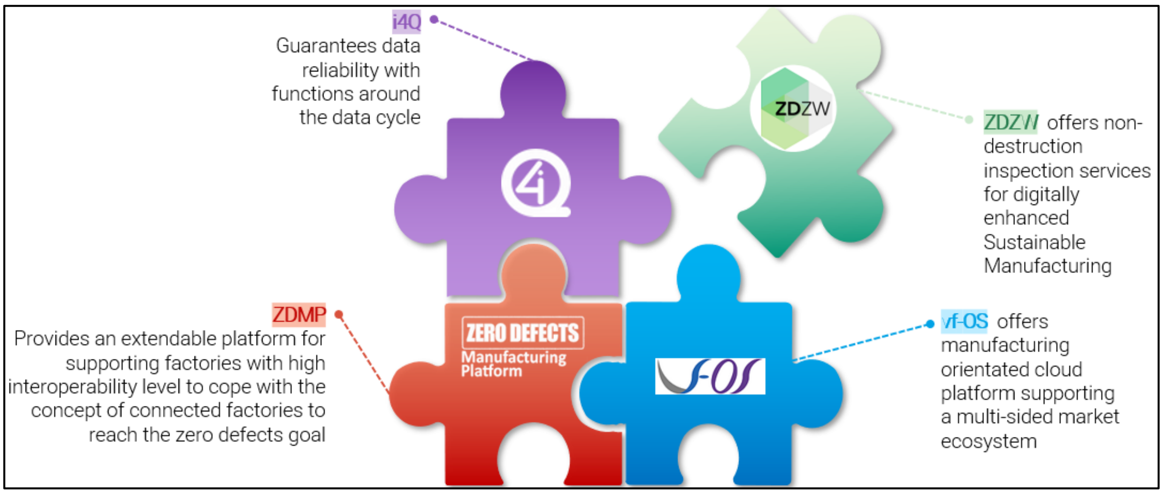


Figure 10. Synergy between i4Q, ZDMP, vf-OS and ZDZW projects.

2.2.11 QU4LITY

Qu4lity[14] is the largest European project focused on Autonomous Quality (AQ) and Zero-Defect Manufacturing (ZDM) in the context of Industry 4.0. Through 14 pilot lines, Qu4lity demonstrates in a practical, measurable, and replicable way how the European industry can create open, certifiable, highly standardized, SME-friendly, and transformative shared data-driven ZDM product and service models for Factory 4.0. The project shows how the European industry can create highly customized ZDM strategies and gain competitive advantages through the use of an orchestrated open platform ecosystem for ZDM and AQ, composed of components, and digital tools that cover the entire product and process lifecycle.

The main goal is to build an autonomous quality model to address the challenges of ZDM in Industry 4.0. Qu4lity enables manufacturers and solution providers, including SMEs, to develop, validate, deploy, and adopt innovative cognitive manufacturing solutions for ZDM. The project provides digital enhancements to existing ZDM equipment and processes, as well as a reference architecture and blueprints for integrating them in factories. Qu4lity also enables the creation of diverse digital manufacturing platforms with cognitive ZDM systems that support the AQ concept.

[14] About • Qu4lity (qu4lity-project.eu)

To facilitate access to AQ solution components and speed up innovation cycles for ZDM, Qu4lity establishes a European innovation ecosystem to promote the development, validation, and wider adoption of ZDM solutions based on the AQ paradigm.

2.2.12 AIP3

AIP3[15] consists of creating a collaborative simulation environment around an MRP based on simple and agile optimisation algorithms. In this way, part of the company's own production or purchasing constraints can be solved manually by the planners themselves. In addition, planners will be provided with a convenient framework, which quickly assesses the implications of any changes made to the plan.

Classic MRP suffers from a lack of foresight in the plans it generates because it does not consider real production capacities, while MRP II and ERPs are very difficult to integrate and require a large amount of data, often unavailable or very difficult to obtain.

In this project we created a collaborative simulation environment that would underpin the optimised MRP, so that part of the company's own production or purchasing constraints would be solved manually by the planners themselves, providing them with a convenient framework that quickly assesses the implications of any changes made to the plan.

In this way, planners can adapt the plans proposed by the optimised MRP to their business requirements, without having to feed the MRP with a lot of data that they probably don't have.

2.2.13 ORP

The ORP project was born from the need to streamline and accelerate the adoption of optimization by companies in our immediate environment. This project has created a platform specialized in the creation, design, and execution of optimization algorithms to solve different optimization problems. The proposed platform is not oriented to a particular decision problem but is intended to be adapted and extended to solve different problems. This platform focuses on reducing both the design, development, and implementation times of the technology, as well as the costs incurred by organizations for its adoption.

To this end, ITI has worked on a solution based on the decomposition of an optimization problem into pieces that can then be combined to form an algorithm. By performing this decomposition process and separating the parts, we can design and create a set of compatible libraries that share certain processes and protocols that will be used to compose algorithms to solve different optimization problems depending on how the composition is done.

In addition, the platform includes libraries and methods that allow solving combinatorial optimisation problems with multiple decision levels and thus be closer to the real problems faced by companies. In addition, this platform also provides some tools that allow access to algorithms, the creation of algorithms at runtime (by combining existing components) and the creation and

[15] AIP3: Proyecto de I+D. Optimiza la programación de la producción (iti.es)

execution of experiments. The developed platform offers libraries, methods and tools for the design, creation, testing, implementation, and execution of optimisation algorithms. Some of its most outstanding features are:

- **Adaptable:** Ease of inclusion in existing processes or tools that require combinatorial optimisation.
- **Flexible:** Allows the rapid creation and adaptation of algorithms, as well as the inclusion of new problems, with the least possible effort.
- **Multi-platform:** It will work on the main operating systems and environments.
- Functional: It makes use of the latest computer technologies to solve new optimisation problems.
- **Verifiable:** The tools and libraries included are tested to verify the security and quality of the resulting software.
- **Scalable:** Allows algorithms to be executed in large systems, taking advantage of computing power, to provide high-quality solutions to real environments.
- **Connectivity:** The framework can connect with external tools and can import input data and export the results obtained using standard formats.
- **Ease of use:** Tools have been developed to accelerate the design, development, and testing of optimisation algorithms, as well as their implementation and execution.

2.2.14 FRACTAL

FRACTAL is a research project that aims to design and develop a reliable computing node that will enable the creation of a Cognitive Edge in accordance with industry standards. This computing node will serve as the foundation for scalable Internet of Things, ranging from low-computing to high-computing Edge Nodes. The cognitive capabilities (i.e., Cognitivity) are provided by AI methods, supported by internal and external architectures that allow the (platform) node to proactively adapt to changes in the surrounding world. Therefore, this node will have the ability to learn to improve its performance in real-time and uncertain conditions.

While the importance of certain features in a computing node cannot be overlooked, it is essential to consider the potential advancements in the realm of Cyber-Physical Systems (CPS), Systems of Systems (SoS), and the Internet of Things (IoT). For example, the potential benefits of advancements in areas such as advanced microelectronics, high-performance computing, smart system integration, and improved cloud services are often overlooked. Neglecting these advancements could result in a computing node that does not meet the demanding requirements for increased autonomy in new application domains. As a result of incorporating these cognitive systems into a fractal network, there will be additional benefits such as safety, adaptability, and the emergence of new possibilities. Therefore, new industrial functions will emerge through the created space of possibilities of our cognitive systems. This scalable fractal network will transfer these cognitive advantages to the Edge, a computing paradigm that sits between the physical world and the cloud.

2.2.15 KIcKER

The German BMBF project KIcKER aims at the development of an AI-assistant for the semi-automatic design and optimisation of an extrusion die to produce polymer profiles (see Figure 11).

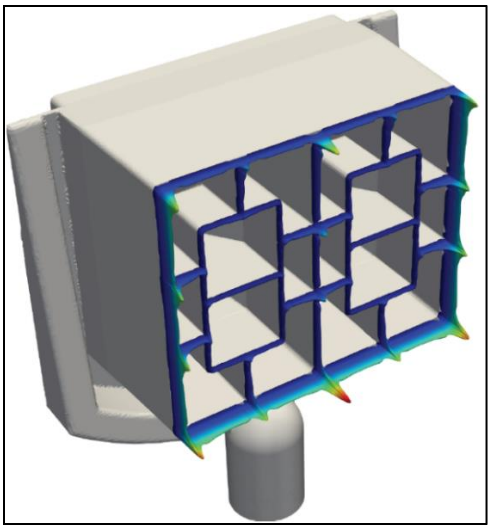


Figure 11. CFD simulation for the velocity distribution of a complex profile die.

The assistant is supposed to deliver the construction data based on a given target profile defined by a 2D target shape. Based on a full parametrization of the die's design space, a Machine Learning-based generative AI trained with parameterizations, construction constraints and corresponding target properties derived from synthetic CFD result data can predict the parameters leading to a specific set of constraints and target properties.

2.2.16 SHOP4CF

The SHOP4CF[16] project started in January 2020 and will end in December 2023. The SHOP4CF project aims to develop a platform on an open architecture encompassing technologies based on RAMI 4.0 and FIWARE technologies, that can support humans in production activities and provide basic implementation as a free, open-source solution. The goal is to be able to find the right balance between cost-effective automation and repetitive tasks while involving human workers in areas such as adaptability, creativity, and agility etc. In addition, to also pursue the highly connected factory model to reap the benefits of all data generated within the factory. The SHOP4CF framework architecture aims at ensuring coherence and interoperability of the SHOP4CF software components. The architecture provides a common template for concrete systems under design. The SHOP4CF architecture conforms to the following reference architectures: ISA-95, RAMI 4.0, FIWARE Smart Industry, and International Data spaces, as well as to the architecture of prior research projects (Figure 12).

[16] SHOP4CF ⋆ SHOP4CF

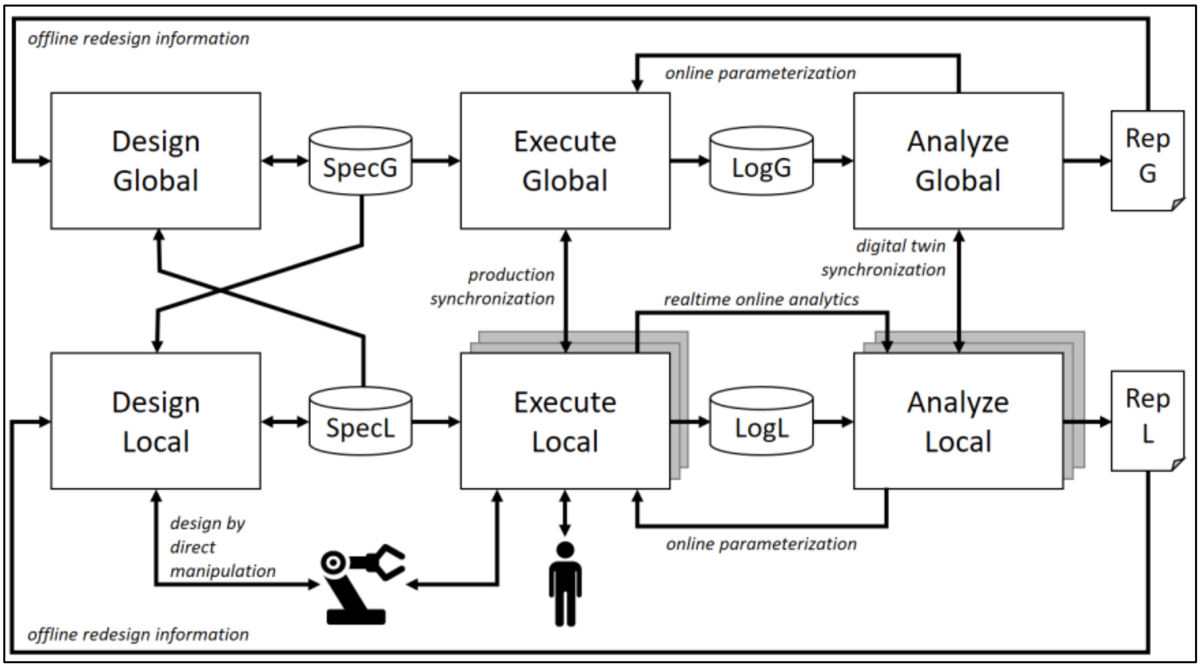


Figure 12. High-level logical software architecture with interfaces.

2.2.17 Potential interest for AIDEAS

AIDEAS is a collaborative project led by a consortium comprising multiple partners. This European initiative, similar to the aforementioned projects, has emerged in response to the needs of the SME market. By leveraging the knowledge garnered from these analogous projects, AIDEAS aims to foster synergies and harness the expertise developed within each project. Among these projects, AI-PRIMS and CLARUS stand out, which focus on integrating workers into the industry, considering important aspects such as environmental impact. These initiatives develop tools based on improvements provided by the cloud and Deep Learning algorithms, emphasizing the use of communication standards and data traceability.

- On the other hand, the TALON project aims to develop an automated architecture utilizing AI, with a specific focus on Edge deployment. This project also emphasizes the incorporation of industry standards to ensure seamless integration and compatibility. Also, TALON aims to optimize industrial processes by incorporating advanced technology into the existing infrastructure.
- The AGILEHAND project offers a range of AI-based tools to monitor, control, and synchronize production with logistics, focusing on the manufacturing lifecycle. These solutions enable greater efficiency in production processes by intelligently integrating different aspects related to logistics.
- C2NET is a completed project based on continuous data collection through a network of resources provided by IoT devices. This data connection is used to monitor and manage the agility of the collaborative process, and it is provided through a cloud platform with the necessary modules to create a collaborative working environment with network partners.
- The vf-OS project presents an architecture that distributes the use of solutions developed by developers and used by customers. This allows for greater flexibility and adaptability

in the implementation of technological solutions, giving customers the opportunity to customize and leverage tools according to their specific needs.

- ZDMP is a project that provides a platform to help factories achieve zero defects in their production processes. By implementing advanced technologies, ZDMP aims to improve the quality and efficiency of manufactured products, contributing to waste reduction and increasing customer satisfaction.
- The i4Q project focuses on the development of solutions to improve product quality. Through the implementation of technologies such as AI and data analysis, i4Q seeks to proactively identify and address quality issues, thus enhancing efficiency and customer satisfaction.
- ZDZW, as part of the set of solutions offered by ZDMP, i4Q, and vf-OS, provides the possibility to improve the quality of products during the usage phase of different machines through pilot implementation. This allows for real-time feedback and adjustments to ensure optimal product quality and performance.
- AIP3 is conceived as a starting point to develop a more robust and faster Material Requirements Planning (MRP) technology. This project aims to improve planning and material management processes in the industry, using advanced technologies such as machine learning and algorithm optimization.
- The ORP project will provide flexible and adaptable optimization algorithms for various problem-solving needs. These algorithms will improve the efficiency and productivity of industrial processes by optimizing resources and reducing response times.
- FACTRAL focuses on providing an infrastructure and analytical platform, defining a framework to transfer the computer paradigm of AI between the physical world and the cloud. This initiative facilitates real-time data processing and analysis, enabling informed decision-making based on accurate and up-to-date information.
- KICKER offers an optimization/prediction system architecture, dimensions, and technological stack in training DoEs (Design of Experiments) and data processing pipelines. This project aims to improve optimization and prediction processes in the industry, using advanced data analysis techniques and machine learning.
- Lastly, the SHOP4CF project focuses on creating industrial applications that facilitate and complement the tasks of human workers. By using technologies such as collaborative robotics and AI, SHOP4CF seeks to enhance productivity and efficiency in industrial environments, fostering collaboration between humans and machines.

In conclusion, the AIDEAS project led collaboratively by various partners demonstrates a strong focus on the application of innovative solutions in the industry. These initiatives address key areas such as worker integration, process optimization, product quality, and collaboration among industry stakeholders. By leveraging advanced technologies such as AI, machine learning, and data analysis, these projects aim to drive efficiency, sustainability, and competitiveness in the industrial environment. From the creation of cloud-based tools and Deep Learning algorithms to the development of automatic architectures and monitoring solutions, each project tackles specific challenges to improve production and product quality. Furthermore, emphasis is placed on the importance of collaboration among different partners and the integration of communication standards and data traceability. This allows for a holistic approach and a more comprehensive understanding of industrial processes, facilitating informed decision-making and efficient implementation of the proposed solutions.

The presented projects not only seek to optimize production processes but also improve quality, reduce defects, and enhance customer satisfaction. Moreover, effective collaboration between human workers and advanced technologies is targeted to complement and facilitate labor tasks.

2.3 Relative Initiatives and Reference Architecture Test Targets

Within Industry 4.0, there is a wide of technologies with different functions that are implemented in different manufacturing processes. The complexity lies in integrating these technologies as a whole system because each of the technologies usually works independently with different types of programming languages and software. Therefore, Industry 4.0 revolutionizes the conventional production process, shifting it from a hierarchical structure adhering to the ISA 99/IEC 62443 standard to an interconnected network model enabled by the Internet of Things (IoT). The primary objective is to identify an appropriate architectural framework that facilitates the integration of Operations Technology (OT) and Information Technology (IT), thereby achieving convergence [26].

Reference architectures (RAs) are fundamental assets that enable system architects to design their systems using a common framework and vocabulary. The design of the RAs is found at a higher level of abstraction, allowing them to identify and understand the most relevant application problems and patterns in an easier and faster way. In addition, RAs allow for building a holistic system, considering different architectural viewpoints to cover all stakeholders' requirements [11].

Within this research domain, there are various reference architectures available, such as the Industrial Internet Reference Architecture (IIRA) proposed by the Industrial Internet Consortium[17] (IIC) and the Reference Architecture Model for Industry 4.0 (RAMI 4.0). These reference architectures play a crucial role as primary sources of information when it comes to designing and developing Industrial Internet Systems (IIS). Both approaches strive to establish a collaborative, data-driven environment that enhances the efficiency of industrial processes.

According to ISO/IEC/IEEE 42010 terminology, the viewpoints comprise conventions that structure the descriptions and analysis of specific system issues. Each viewpoint delineates one or more concerns, which are topics of interest related to the system. On the other hand, stakeholders encompass individuals, workers, departments, and other entities interested in the respective concerns and, consequently, in both the viewpoint and the system itself. To aid in describing, analyzing, and resolving problems, one or more modelling constructs can be defined as the classes of models for each viewpoint. The combination of viewpoint constructs, stakeholders, concerns, and model types forms the architecture framework.

Therefore, the focus of this stage will be on developing the AIDEAS framework. By accurately defining the information system, companies can effectively gather, exchange, transmit, and analyze all the data generated throughout the manufacturing process. The main goal is to leverage AI tools to improve the sustainability, agility, and resilience of machinery manufacturing companies. As a result, it is considered a best practice to carefully consider architectural decisions

[17] https://www.iiconsortium.org/

and strive to align them with the expectations of all stakeholders involved. Below are some of the most relevant architectures of the moment and on which its experience has been based to develop the entire AIDEAS ecosystem.

2.3.1 The Industrial Internet Reference Architecture (IIRA)

IIRA is a standards-based open architecture for industrial Internet systems, intended to increase industry interoperability and guide the development of technical standards. IIRA is a generic architecture with a high level of abstraction that supports broad industrial applicability based on use cases defined by the IIC. IIRA has been published by the IIC in 2019 in the document "The Industrial Internet of Things Volume G1: Reference Architecture" which has a new version in 2022 called "The Industrial Internet Reference Architecture" and contains architectural concepts, vocabulary, structures, patterns, and a methodology for addressing design concerns [19]. The document identifies the fundamental architecture constructs and specifies design issues, stakeholders, viewpoints, models, and conditions of applicability defining a framework by adapting architectural approaches from the ISO/IEC/IEEE 42010-2011.

2.3.1.1 Overview

The IIRA uses the same basic ideas and elements found in the ISO/IEC/IEE architecture description specification (such as concern, stakeholder, view, and viewpoint) as its framework for describing and analyzing key architecture concerns for IIoT systems. IIRA utilizes views and models as its method of representing these architectures.

The views can be used as a starting point for specific architecting, helping to create an abstract architecture that addresses concerns, extended, and enhanced with specific use case requirements, according to the needs of the specific IIoT system architecture (Figure 13).

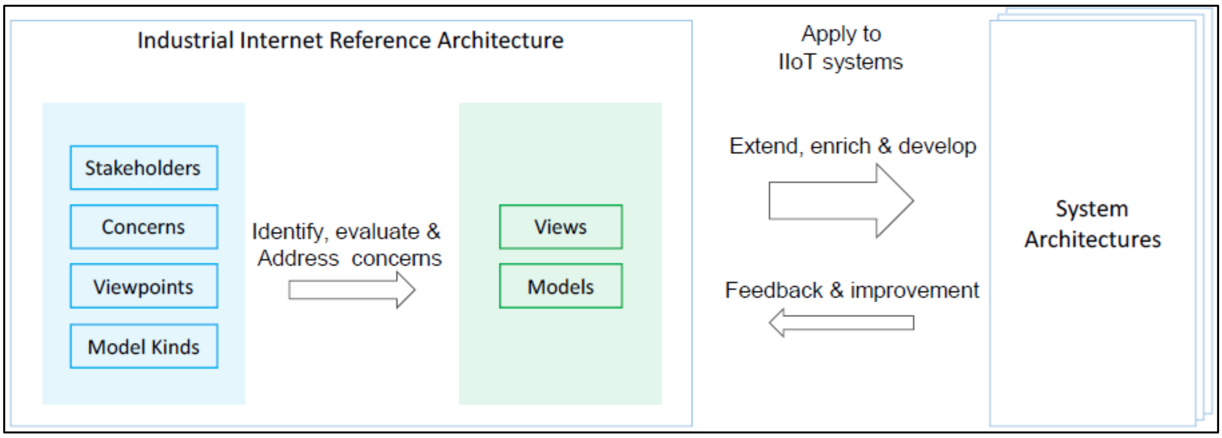


Figure 13. The key ideas in the IIRA and its application [11]

The IIRA aims to pinpoint the crucial and predominant architecture concerns in IIoT systems. It offers a framework and approach for engineers to assess and solve design problems. Furthermore, the framework and approach guide the designers on how to tackle the major concerns, by analyzing architecture patterns, which would aid the Industrial Internet of Things (IIoT) system designers to avoid overlooking important architecture elements and also discovering missing functions or components in the design.

Hence, the reference architecture is designed to be a generic framework that identifies common architecture patterns that can be applied to various industrial internet applications across different industries. Therefore, it is presented at a high level of abstraction and its concepts and models are at a high degree of generality. When this general framework is applied to specific usage scenarios, it can be transformed and extended to create detailed architectures that address the unique requirements of those scenarios, guiding the next phase of architecture and system design. The IIC will gather feedback from practical implementations across different industries, including from various IIC testbed initiatives, to determine the effectiveness and usefulness of the reference architecture in the system-design process, and may make revisions and improvements as needed.

2.3.1.2 Main features

The IIRA methodology is a system conceptualization tool that helps architects and engineers identify and resolve key design issues in Industrial Internet of Things Architecture. The IIRA design process starts by determining the structure and layout of an IIoT system by considering the perspectives of stakeholders. To achieve this, IIRA viewpoints are created by studying various IIoT scenarios from the IIC and other sources, recognizing the key players involved in IIoT systems, and determining the appropriate focus for each viewpoint (Figure 13). These IIRA viewpoints are arranged in a specific order to mirror the interaction patterns that occur between them, as decisions made in a higher-level viewpoint impose needs on the viewpoints beneath it. In this way, the IIRA method offers a structured approach to guide the system design, development and maintenance. These four viewpoints are [11]:

- **The Business Viewpoint:** Identifies the parties involved in the creation, deployment, and maintenance of an IoT system, and their business goals and objectives. It considers the general business and regulatory environment in which the IoT system operates.
- **The Usage Viewpoint:** Addresses the concerns related to how the system is intended to be used and is typically represented as sequences of activities involving human or logical users that deliver its intended functionality. Stakeholders of these concerns typically consist of system engineers, product managers and others, including those involved in the specification of the IIoT system and those who use it.
- **The Functional Viewpoint:** Focuses on the functional components in an IIoT system, their organization and interconnectedness, the interfaces and interactions among these components, as well as the system's relationship and interactions with external elements in its environment. This analysis aims to facilitate the intended usage and activities of the entire system.
- **The Implementation Viewpoint:** Addresses the concerns related to the technologies, communication schemes and lifecycle procedures necessary to implement the functional components (functional view) and support the system capabilities (business view) and activities (usage view). These elements are of particular interest to system and component architects, developers, integrators, and system operators. The implementation view includes architecture pattern models, which describe the structure of a system and are used in the construction of new systems, using both common architecture frameworks and specific domain languages.

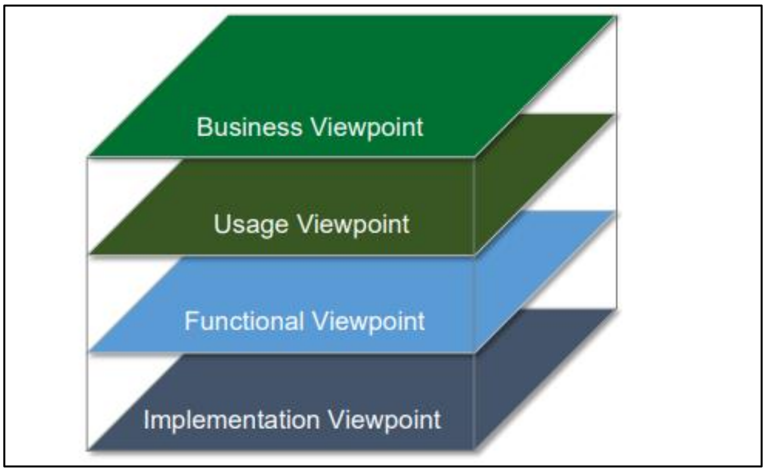


Figure 14. IIRA Architecture Framework [10]

The IIRA addresses issues that extend beyond the design phase of a system and into its entire lifecycle. It guides the process of creating an IIoT system from conception to implementation through its viewpoints, which provide a framework for designers to consider key architectural issues. It also suggests common concepts and models as views in each viewpoint to help identify and solve important architectural issues. Figure 15 illustrates the mechanism of the interaction between each viewpoint, from the business viewpoint to the implementation viewpoint the architecture is built guided in the order of the layers, after the implementation, the architecture can be revised and validated downstream.

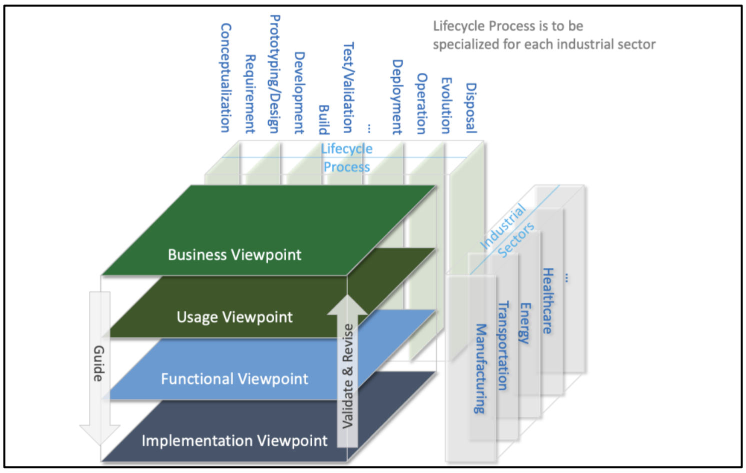


Figure 15. Relationship among IIRA Viewpoints [11]

The functional viewpoint is the most crucial aspect in creating and implementing an IoT system, according to the IIRA. This viewpoint breaks down the system into specific functionalities, known as functional domains. These domains are fundamental components that can be used across various industries and applications. The IIRA specifically separates an IoT system into five functional domains: control, operations, information, application, and business.

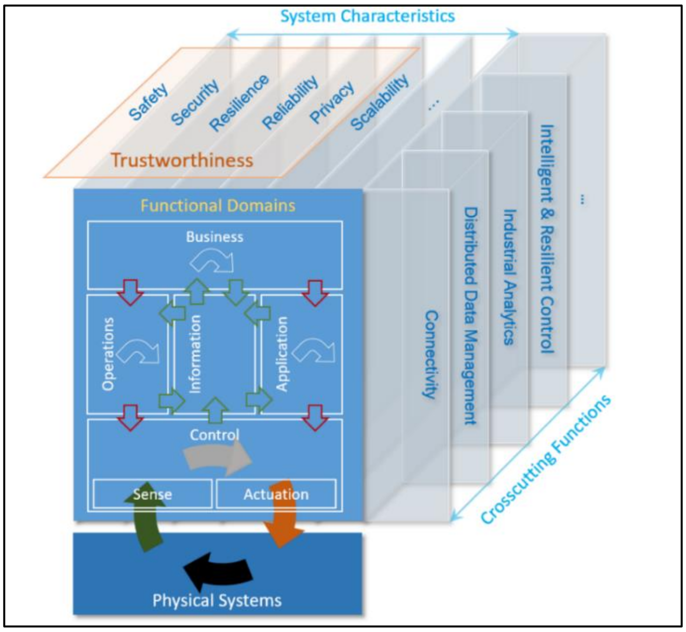


Figure 16. Functional Domains, Cross-Cutting Functions and System Characteristics as specified in the IIRA [11]

2.3.2 Reference Architectural Model Industrie 4.0 (RAMI 4.0)

The Plattform Industrie 4.0 established the Reference Architectural Model Industrie 4.0 (RAMI 4.0) in 2015 with a focus on the Internet of Things (IoT) and Cyber-Physical Systems (CPS) in the industrial manufacturing sector. To put Industry 4.0 into practice, RAMI 4.0 is a critical first step. Along the entire value chain, the model can represent technical items, often known as "assets", which can be either tangible or immaterial. This model's objective is to reflect the technical object and all pertinent aspects of it, from its conception and development to its manufacture, usage, and disposal. The model also illustrates the level, phase, and interactions that each "Industry 4.0 component" has with other higher-level components.

RAMI 4.0 was almost the same time the Industrial Consortium (IIC) promoted the Industrial Internet Reference Architecture (IIRA). A unified foundation for sophisticated industrial information and communication technologies, as well as automation and production technologies, is what both architectures aim to define.

2.3.2.1 Overview

Recently, RAMI 4.0 has been successfully recognized in national and international standardization committees and cooperations as the DIN standard (DIN SPEC 91345:2016) and international pre-standard (IEC PAS 63088:2017). **DIN SPEC 91345:2016-04** describes two basic reference models for the **Industry 4.0** concept:

- The reference architecture model RAMI4.0 is a reference model for the reference architecture Industry 4.0 and is used for the structured description of basic ideas.
- The reference model I4.0 component is used to make this description accessible in terms of data technology.

Additionally, a virtual representation of assets is crucial to defining the structure and functionality of the Industry 4.0 component. RAMI 4.0 consists of a three-dimensional coordinate system composed of three axes: **Life Cycle/Value Streams, Layers** and **Hierarchy Levels**, which shows how to approach the issue of Industry 4.0 in a structured manner (Figure 14). RAMI 4.0 ensures that all participants involved in Industry 4.0 discussions understand each other. As a reference architecture model, RAMI 4.0 offers the chance to identify the standards needed for Industry 4.0 use cases by uncovering potential use cases. This procedure examines concepts and techniques in the appropriate measures to determine how well-suited they are for use in the Industry 4.0 environment [15]. Also, the integration of the physical asset and its digital representation is proposed relying on a common representation called the Asset Administration Shell (AAS). Analyzing each of the dimensions presented in RAMI 4.0:

- **Life Cycle/Value Streams:** The left horizontal axis in the life-cycle management model represents the stages of development and usage of facilities and products in the industrial-process measurement, control, and automation industry, as defined by IEC 62890. In this model, a distinction is made between "types" and "instances" of products. A "type" represents a product's initial idea and design, while an "instance" refers to the product being manufactured. This model also incorporates all elements and IT components in the life-cycle management process. The Type section is further divided into Development and Maintenance/Usage, while the Instance section is divided into Production and Maintenance/Usage. This means that when a product is still in the development phase, it is considered a "Type"; once it enters production, it becomes an "Instance". Whenever a product is redesigned, or a new feature is added to it, then again, its state turns to "Type". With the ability to link purchasing, production planning, logistics, quality, customers and suppliers, the lifecycle management provides a clear view of the value-adding process in totally digitized production.
- **Architecture Layer:** This is a key component in the development of Industry 4.0 software solutions. It includes six layers on the vertical axis that describe the decomposition of a machine into its properties, structured layer by layer, i.e., the virtual mapping of a machine. These representations originate from information and communication technology, where properties of complex systems are commonly broken down into layers. This layer enables the development of Industry 4.0 software solutions in a consistent way so that different and mutually dependent manufacturing operations are interconnected, taking into account both the physical and digital worlds.
- **Hierarchy Levels:** The Industry 4.0 environment is characterized by an advanced level of automation and connectivity, with a focus on optimizing industrial processes and increasing efficiency. One way to represent this environment is by hierarchy levels, as defined by the international standards series IEC 62264. These levels represent the different functionalities within factories or facilities and include Products, Field Devices, Control Devices, Station, Work Centers, Enterprises, and Connected World. The IEC 62243 standard, which is based on ANSI/ISA-95, is also used to depict these functionalities, but with an expansion to include work pieces and the connection to the Internet of Things and services. In addition to these functionalities, the Industry 4.0 architecture also includes a functional assignment of components and the ability to follow the IEC 61512 standards at the hierarchical level. This axis within an enterprise or factory represents further steps and describes groups of factories, collaboration within external engineering firms, component suppliers and customers.

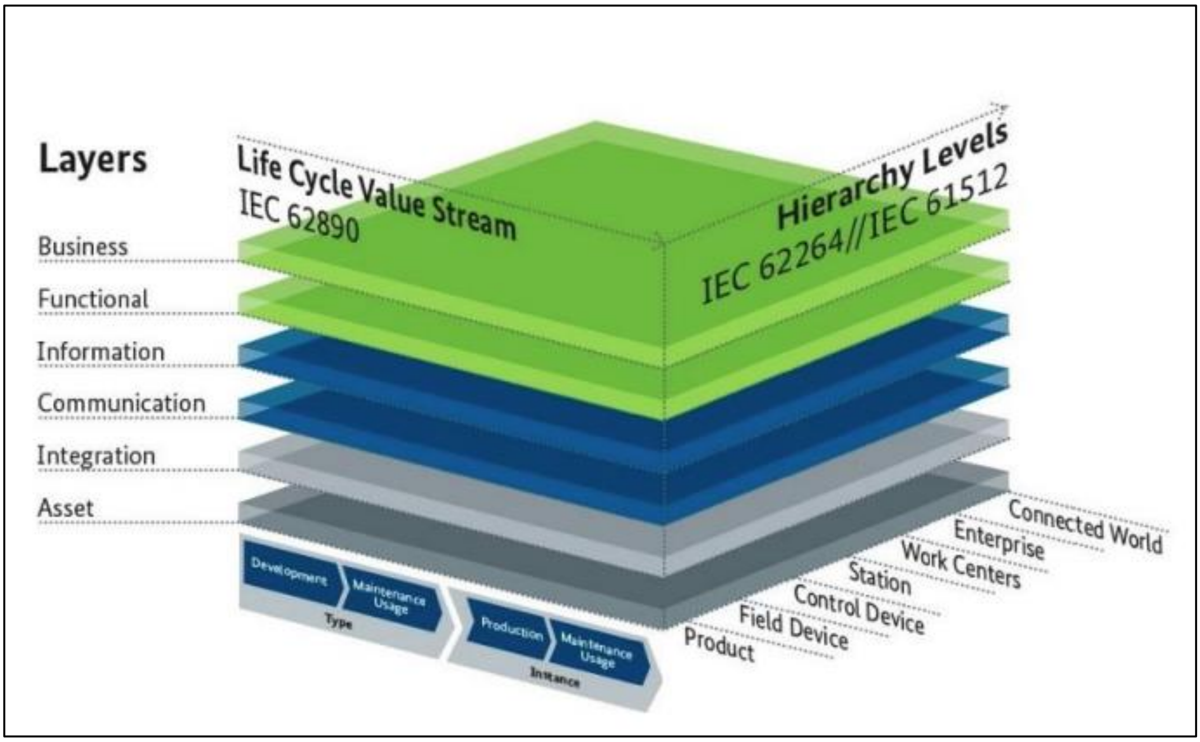


Figure 17. The three dimensions of the RAMI 4.0[18].

2.3.2.2 Main features

RAMI 4.0 gives applications that use the Internet of Things (IoT), big data analytics, and other technological advancements in manufacturing processes—also known as smart manufacturing, intelligent manufacturing, or simply Industry 4.0—a reference architectural model that is solution-neutral. The ability to communicate, the system's scope and design, as well as to promote collaboration and integration with other pertinent projects, is one of the key goals once it has been adopted. This is done by framing the developed concepts and technology in a common model. RAMI 4.0 can be viewed as a sort of 3D map of Industry 4.0 solutions; it offers a framework for mapping industry standards and national and international needs to define and advance Industry 4.0. Thus, gaps and overlapping standards can be found and fixed [14].

Standards and use-cases can be positioned using the three-dimensional matrix. End-to-end engineering, human value-stream orchestration, and integration within and between factories are all addressed. The elements of Industry 4.0 complete this concept, and both have been explained in (DINSPEC91345:2016-04, 2016). Each component in RAMI4.0 has six layers. The structure, which is depicted in the below picture as a layered IT system structure, is composed of business, functional, information, communication, integration, and asset layers.

[18] Reference Architectural Model Industrie 4.0 (RAMI 4.0) (europa.eu)

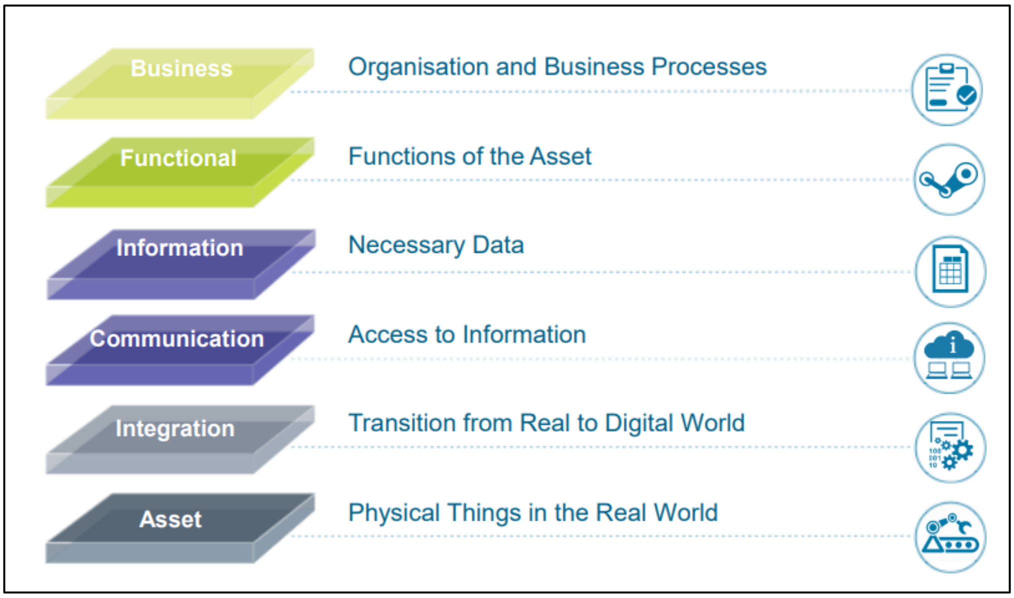


Figure 18. Architecture Layers of the RAMI 4.0 [19].

Analyzing each of the layers based on [7]:

- **Business layer**: Depicts the overall process, the system´s regulations, and the business model. The value stream´s functions are integrated into the business model layer. It also outlines the legal and regulatory framework requirements. The functional layer´s services are coordinated by the business layer, which also receives events that provide updates on how the business process is doing.
- **Functional layer**: It gives the services that provide the business layer with the runtime and modelling environment. Except for operations only pertinent to lower layers (such as reading diagnosis data) or are solely relevant to lower layers (such as reading diagnosis data) or that are not important to ongoing functional or horizontal integration, remote access and horizontal integration occur in the active layer.
- **Information layer:** It contains the data services that allow the data to be used, generated, and maintained as a result of the technical functionalities of the assets. This covers data integrity, provisioning, integration, and persistence. It applies the necessary processing and transformation to events received from the physical help through lower-level layers to order to enable the functional layer services.
- **Communication layer:** Offers standard communication and data formats that enable information access and interfaces to use an asset's features from other investments. The communication layer places focus on describing protocols and processes for the interoperable exchange of information across components.
- **Integration layer:** Symbolizes the change from the physical to the digital realm. The integration layer reports events from the physical world and represents a representation of an asset's attributes and process-related functions. Asset documentation, software, and firmware, or Human-Machine Interfaces, are all included in the integration layer (HMI).

[19] Reference Architectural Model Industrie 4.0 (RAMI 4.0) (europa.eu)

- **Asset layer:** The physical distribution of each participating component in the context of the smart grid is the focus of the component layer. This encompasses physical objects, software programs, system actors, papers, concepts, and people.

Asset Administration Shell

The Asset Administration Shell (AAS) is a collection of information and tools that are used to manage a specific asset within a company or organization. This collection of information is linked to a specific asset and can be found and explored within the company's Industry 4.0 network. Additionally, the AAS controls who has access to the asset it manages [27]. The AAS can be provided in different implementation variants:

- **Passive,** e.g., when the information is delivered via a file or via IP/API based access. In these cases, the requested AAS is provided following a client/server model.
- **Active** refers to a peer-to-peer interaction pattern. Administrative modules can communicate with each other using Industry 4.0 language.

Starting from the above classification AAS implementation can be assigned in the RAMI4.0 Model covering different layers. RAMI4.0 can be used to show how the passive and active AAS differ from one another. In the form of so-called submodels, the passive administration shells provide descriptions of the features, parameters, variables, and process capabilities. Other components can access, read, and alter this abstraction of assets. The ability to respond to requests and directives from outside sources and the inability to take the initiative and make decisions to further one's own objectives are both passive aspects of this type of AAS. On the other hand, the term "active" describes the autonomous activation of contact with external AASs, such as in the context of a goal that is being sought (e.g. to act as economically as possible) (Belyaev & Diedrich, 2019).

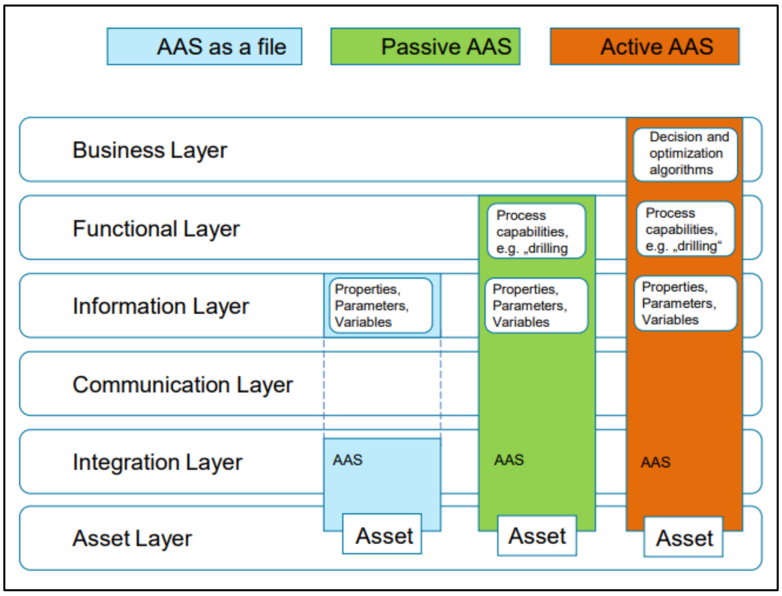


Figure 19. Assignment of the active AAS in the RAMI4.0 – Model (Belyaev & Diedrich, 2019).

Everything that can be connected to construct an Industry 4.0 solution is a resource (i.e., machinery, parts, supply material, documents, contracts, etc.). The AAS also specifies a package file format (the Asset Administration Shell Package, AASX), for exchanging the entire or a portion of the administrative shell's structure, as well as data models for information interchange between participants in the value chain [7].

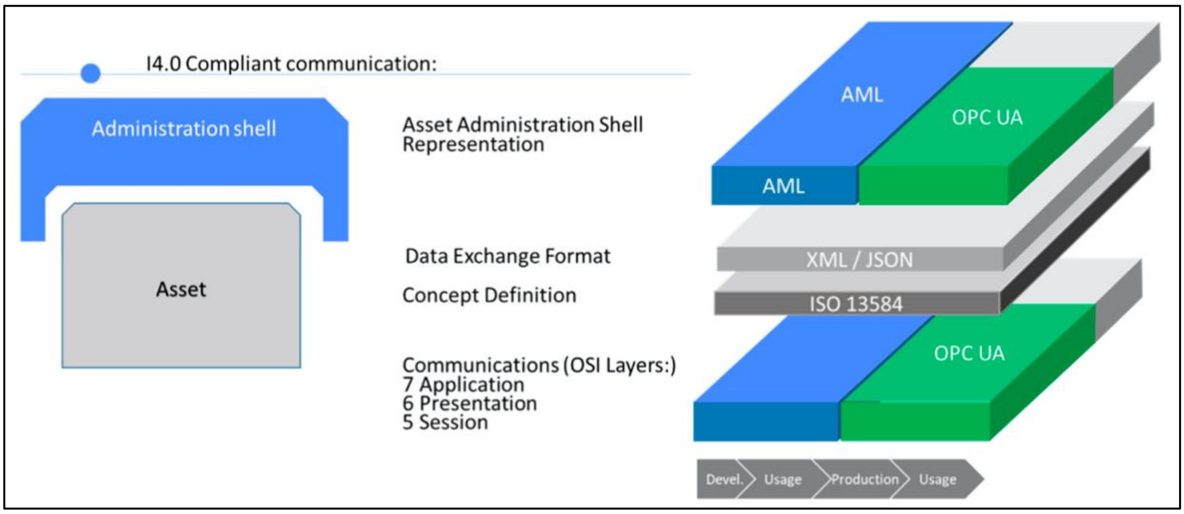


Figure 20. I4.0 Communication protocol stack.

The AAS (Asset Administration Shell) incorporates the principles of the Digital Twin concept to fulfill the diverse requirements of various use cases across different domains, ensuring:

- **Interoperability** enables seamless communication and information exchange between companies.
- **Availability**, accommodating both non-intelligent and intelligent products.
- **Integration**, facilitating the seamless integration of various components within the value chain.
- **Comprehensive coverage** of the entire life cycle of products, devices, facilities, and more.
- **Serving as a foundation** for autonomous systems and AI applications.

2.3.3 IoT Reference Architecture ISO IEC 30141

The ISO/IEC 30141:2018 standard for the Internet of Things (IoT) - Reference Architecture, establishes a consistent terminology for constructing and creating IoT applications. This standard is associated with advancements and digital transformation, and serves as a practical guide for the industry, along with a common language and reusable design components.

2.3.3.1 Overview

The IoT RA offers a comprehensive architectural and structural framework that outlines a structured approach for constructing IoT systems. Its goal is to enhance the comprehension of IoT systems among critical stakeholders such as device manufacturers, application developers, consumers, and users. Additionally, it serves as a guide for architects to design IoT systemsFigure 21 illustrates how the IoT RA is derived from a Conceptual Model and a set of characteristics that define a Reference Model (RM) and one or more architectural views.

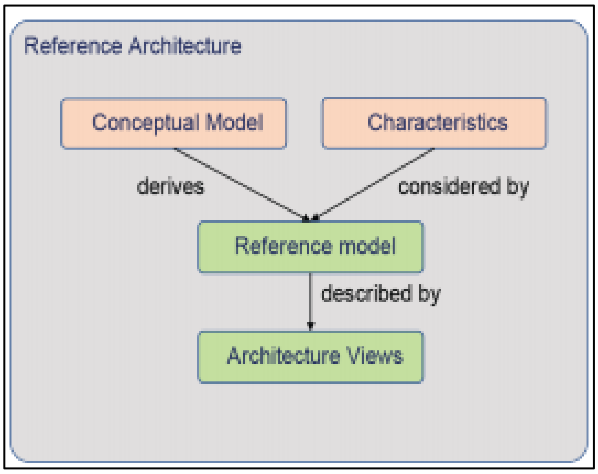


Figure 21. IoT RA structure (ISO/IEC 30141:2018).

Characteristics: Functions based on all, or a part of the characteristics can be implemented in IoT systems. Some of these characteristics are functional, such as network connectivity, while others are non-functional, such as availability and compliance. Different application specialisations can differ regarding the actual quantification of these properties. Still, an IoT architect needs to consider how vital the respective categories are for the designed system. There are no characteristics that are required of any IoT system.

Conceptual Model: The Conceptual Model (CM) encompasses essential concepts and their logical interconnections. Alongside its general attributes, it establishes the foundation and rationale for the architectural elements explored in the architectural views. The CM offers a unified framework and precise definitions for illustrating the concepts and relationships among entities within IoT systems. Its objective is to be broad, abstract, and straightforward in nature. It is important to clarify the fundamentals of IoT systems to achieve this goal by asking the following questions.

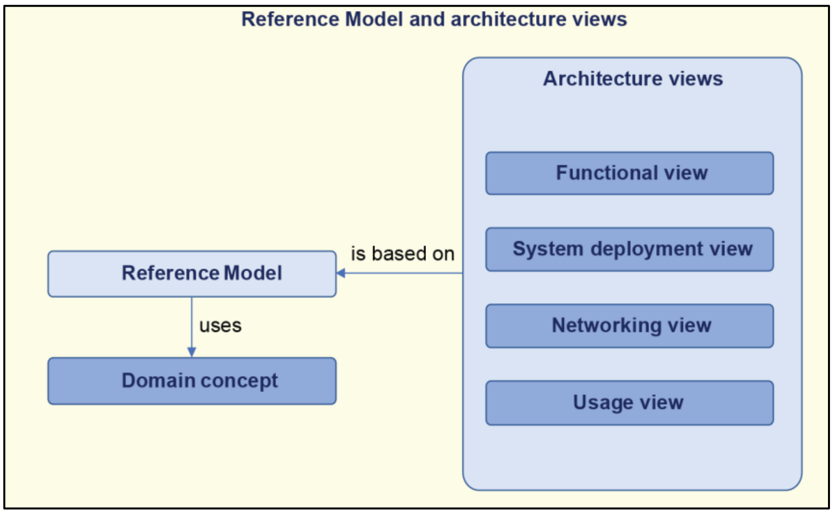


Figure 22. RM and architecture views [8]

As shown in Figure 22, the RM is described by the Architecture Views, but this relationship also happens in reverse; the Architecture Views is based on the RM. The Architecture views are composed of a functional, system deployment, networking, and usage view.

On the other hand, the concept of a domain is used to define the RM. A domain refers to a significant functional grouping within an IoT system, where every entity within the system is associated with one or more domains and is included or contained by those domains.

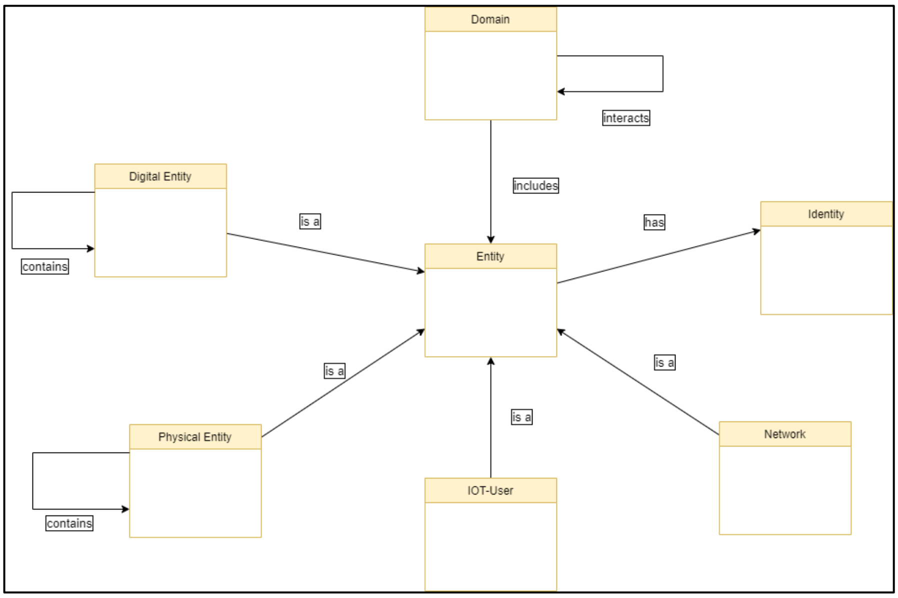


Figure 23. Entity and domain concepts of the CM. based on source: ISO/IEC 30141:2018.

The illustration in Figure 23 shows the concepts of entities and domains within the CM. An entity is defined as a distinct and autonomous entity, such as a person, organization, device, subsystem or group of items. All elements within an IoT system are considered entities. To simplify the understanding of IoT entities and their relationships, four fundamental entities are identified: physical entities (the thing), IoT users, digital entities (IT systems), and communication networks.

2.3.3.2 Main features

The following four RA views describe the IoT RA:

- **IoT RA functional view.** The functional view is a technology-agnostic view of the functional components necessary to form an IoT system. It explains the organisation and connections of the supporting activities outlined in the usage view and covers internal and external functions. Each functional component is carried out by one or more basic system components, which can be combined to create a functioning system.
- **IoT RA system deployment view.** The system deployment view outlines the building blocks used to construct an IoT system, such as devices, subsystems, and networks. In contrast, the functional view depicts an IoT system based on its functional components, whereas the system deployment view describes it based on the components used in the implementation.
- **IoT RA networking view.** The IoT RA networking view describes the main communication networks involved in IoT systems and the entities they connect with. These interconnected networks provide communication connectivity, including data links, and maintain connectivity from one network to another. The networks play a critical role in supporting and providing communication and data exchange activities and interactions between entities, domains, and IoT systems. Inter-domain communication networks, such as local area networks, the Internet,

intranet, enterprise backbone network, vast area network, and B2B networks, are also important for IoT systems.

- **IoT RA usage view.** While the functional view illustrates the required functions and connections of the IoT system, the usage view concentrates on the user's perspective of how the IoT system is built, examined, run and utilised. This view covers tasks, positions and sub-positions, offerings and aspects that cut across multiple areas.

2.3.4 The Intelligent Manufacturing System Architecture (IMSA)

The Intelligent Manufacturing System Architecture (IMSA) is a framework for the design and implementation of intelligent manufacturing systems. It provides a high-level view of the various components and their interactions within an intelligent manufacturing system, including the manufacturing resources, information systems, and control systems.

The IMSA framework also includes guidelines for integrating and coordinating these different components to achieve optimal performance and efficiency in the manufacturing process. Additionally, it includes the usage of AI, IoT, and other cutting-edge technologies to achieve smart manufacturing. The main goal of IMSA is to improve the flexibility, adaptability, and intelligence of manufacturing systems [23].

2.3.4.1 Overview

IMSA is a concept that combines the activities of manufacturing and IT-based functions to make both the production process and the product more intelligent. The main ideas of IMSA construction include setting up a dimension of the product lifecycle and a dimension of a factory as the fundamental plane, also known as the X-axis and Y-axis of the IMSA [28].

The dimension of the product lifecycle includes activities such as design, production, logistics, sales, and service, and includes the process of turning a factory or a plant from a draft into an entity until its destruction. The dimension of the factory called the system hierarchy, follows the manufacturing pyramids in IEC 62264 and includes levels such as equipment, control, workshop, enterprise, and cooperation. The cooperation level illustrates the design and manufacturing cooperation among value chains and within cross-region enterprises.

The lifecycle dimension reflects end-to-end integration, the first four levels of the system hierarchy dimension reflect vertical integration, and the cooperation level of the system hierarchy dimension reflects horizontal integration. After setting up the fundamental plane of manufacturing with the lifecycle dimension and the system hierarchy dimension, a dimension representing IT-based functions is added as the Z-axis of the IMSA [28].

The intelligent functions include five layers, namely resource elements, system integration, interconnection, information fusion, and new business patterns. Data is used as an example to demonstrate the function of each layer. The resources elements layer generates data, the system integration layer collects data, the interconnection layer transmits data, the information fusion layer stores and analyses data, and the new business pattern layer applies the data from different angles.

Safety and IT security are considered in all manufacturing activities and IT function layers and the system integration layer serves as the boundary between the cyber world and the physical world.

Entities in the physical world are included in the resources elements layer, while the mirror mapping of entities, the logic of controlling and computing based on the data they generate, are included in the interconnection layer, information fusion layer, and new business pattern layer [28].

2.3.4.2 Main features

The Intelligent Manufacturing System Architecture (IMSA) is constructed from three main dimensions: lifecycle, system hierarchy, and intelligent functions.

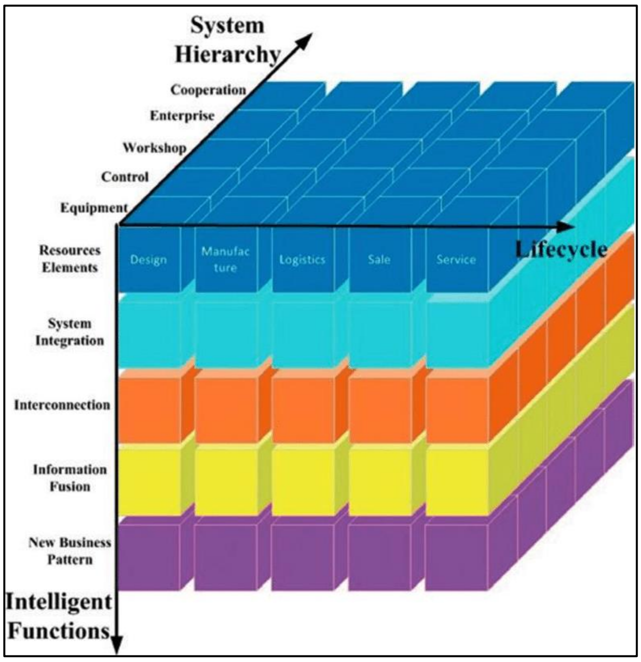


Figure 24. Intelligent Manufacturing System Architecture IMSA. [21]

- The **lifecycle dimension** is a sequence of interconnected activities that create value, such as design, manufacturing, logistics, sales, and customer service. These activities are interrelated and can affect one another. The specific stages of the lifecycle can vary depending on the industry. **Design** encompasses the process of research and development, simulation, verification, optimization and other activities that are carried out in accordance with the needs of the enterprise and the limitations of the chosen technology. **Manufacturing** is the process of producing goods through labour. **Logistics** deals with the transportation of goods to their destinations. **Sales** refers to the transfer of products or commodities from the enterprise to the customers. **Service** includes a series of activities and resulting actions that occur during communication between service providers and customers, including activities such as recycling.
- The **system hierarchy dimension** is organized in a layered structure, with the equipment level at the bottom, followed by the control level, workshop level, enterprise level, and cooperation level at the top. The system hierarchy incorporates the integration of intelligence and internet protocols, as well as a flattened network structure. Specifically, the **equipment** level serves as the technical foundation for production activities and includes sensors. The **control** level includes programmable logic controllers (PLCs), SCADA systems, distributive control systems (DCS), and field bus control systems (FCS). The **workshop** level mainly deals with factory/workshop production management and includes MES systems. The **enterprise** level focuses on enterprise operation management and includes ERP, PLM, SCM, and CRM. The

cooperation level enables coordinated R&D, intelligent production, precise logistics, and intelligent service through the sharing of information over the internet among different enterprises in the industrial chain.

- Utilizing the latest generation of information and communication technology, manufacturing processes have been enhanced with various intelligent capabilities such as self-sensing, self-learning, self-decision-making, self-execution, and self-adaptation. These **intelligent functions** include the integration of resources, interconnectedness and collaboration, information fusion, system integration, and new business models. **Resources elements** refer to the digital process of using resources or tools by the enterprise during the manufacturing process.
- **System integration** refers to the integration of intelligent equipment in intelligent production units, lines, digital workshops, factories, and even intelligent manufacturing systems by the enterprise. **Interconnection** and interworking refer to connecting equipment, systems, and between enterprises through wired, wireless and other communication technology. **Information fusion** refers to the collaborative sharing of information using cloud computing, big data, and other new generation of information technologies. It also includes the use of communication technology based on interconnection and interworking to ensure the safety of the information. The **new business pattern** refers to the integration of the value chain between enterprises to form new industry configurations for the enterprise.

2.3.5 IDS Reference Architecture

The IDSA (International Data Space Association) Reference Architecture Model (IDS-RAM) is a framework that is used to guide the design and development of data systems within the context of the International Data Space (IDS). The IDS is an initiative that aims to create a global platform for exchanging data in a secure, trustworthy, and interoperable manner. This architecture model is developed by the International Data Spaces Association (IDSA), which is a non-profit organization that promotes the use of data-driven systems in various sectors, such as industry, research, and government.

2.3.5.1 Overview

The IDSA Reference Architecture Model provides a high-level overview of the components and functionalities that are necessary to build and operate an IDS, and it serves as a guide for organizations that are interested in participating in the IDS ecosystem. Moreover, IDS-RAM is characterized by an open architecture, reliable and federated for cross-sector data exchange, facilitating sovereignty and interoperability.

2.3.5.2 Main features

This architecture establishes a series of standardized roles and interactions through a 5-layer structure (business, functional, process, information, and system) that are addressed from the perspective of security, certification, and governance. These layers are critical to ensure the success of a data-sharing initiative and are described below:

- The **Business Layer** specifies and categorizes the different existing roles (e.g., Data Owner, Data Provider, Vocabulary Provider…) that the participants of the IDS can assume, and it specifies the main activities and interactions connected with each of these roles, including contracts and data usage policies. The Business Layer plays a role in enforcing data governance policies and ensuring that data is used in a responsible and ethical manner.

- The **Functional Layer** defines the functional requirements of the IDS, and the features to be implemented resulting thereof. These requirements can be divided into the following six groups of software functionality to be provided by the IDS: trust, security and data sovereignty, ecosystem of data, standardized interoperability, value-adding apps, and data markets.
- The **Process Layer** captures the interactions that take place within the data space (between the different components of the IDS). This layer includes processes such as onboarding (what to do to be granted access to the IDS as a Data Provider or Data Consumer) or those processes required for data exchange between IDS participants (Exchanging Data) and the publication and use of data apps (interacting with an IDS App Store or using IDS Data Apps).
- The **Information Layer** explains the Information Model and the common vocabulary to be used to facilitate compatibility and interoperability, which is a core agreement shared by IDS participants and components. This model is generic and enables an automated exchange of digital resources within a trusted ecosystem of distributed parties while preserving the data sovereignty of the Data Owners.
- The **System Layer** assigns a concrete architecture of data and services to each role in order to guarantee functional requirements.

2.3.6 Non-Destructive Kit for Industry 4.0 Evaluation (NIKI 4.0)

An open-source prototype for the NIKI 4.0 project was published at the start of December 2017 by the research partners Hahn-Schickard, the FZI Research Centre for Computer Science, and the University of Applied Sciences Offenburg. As a result, small and medium-sized businesses have the chance to test an Industry 4.0 environment and evaluate the potential benefits of switching to relevant manufacturing. Particularly in smaller businesses, the ideas of Industry 4.0 are received with scepticism, especially since adoption typically necessitates significant investments. The German Federal Ministry of Economics, in collaboration with other research institutions like the Fraunhofer Institute for Production Technology and Automation IPA, actively encourages entrepreneurial tests like those made possible within the framework of the NIKI 4.0 project and it also provides information and advice on technological change [12].

2.3.6.1 Overview

The project 'Non-Destructive Kit for Industry 4.0 Evaluation' (NIKI 4.0 for short) will realise a kit for SMEs with which existing production facilities can be easily and inexpensively extended by means of non-destructive ad-hoc sensor technology and information couplers. The special feature is that production plants and machines remain unchanged and production processes are not initially affected by the acquisition of additional data. SMEs receive a kit that can be installed quickly, affordably, and risk-free to test and evaluate the potential of individual design behind migration to Industry 4.0, along with the communication gateway, which is also a component of the NIKI 4.0 kit, and the visualisation of collected data based on augmented reality. Additionally, as an open-source platform, NIKI 4.0 provides a foundation for customized expansions and adaptations. Due to this, NIKI 4.0 is not only a platform for evaluating specific Industry 4.0 design potentials in SMEs, but it can also be used as the foundation for developing new Industry 4.0 assessment and migration kits, as well as whole new business models that make use of the NIKI 4.0 kit.

2.3.6.2 *Main features*

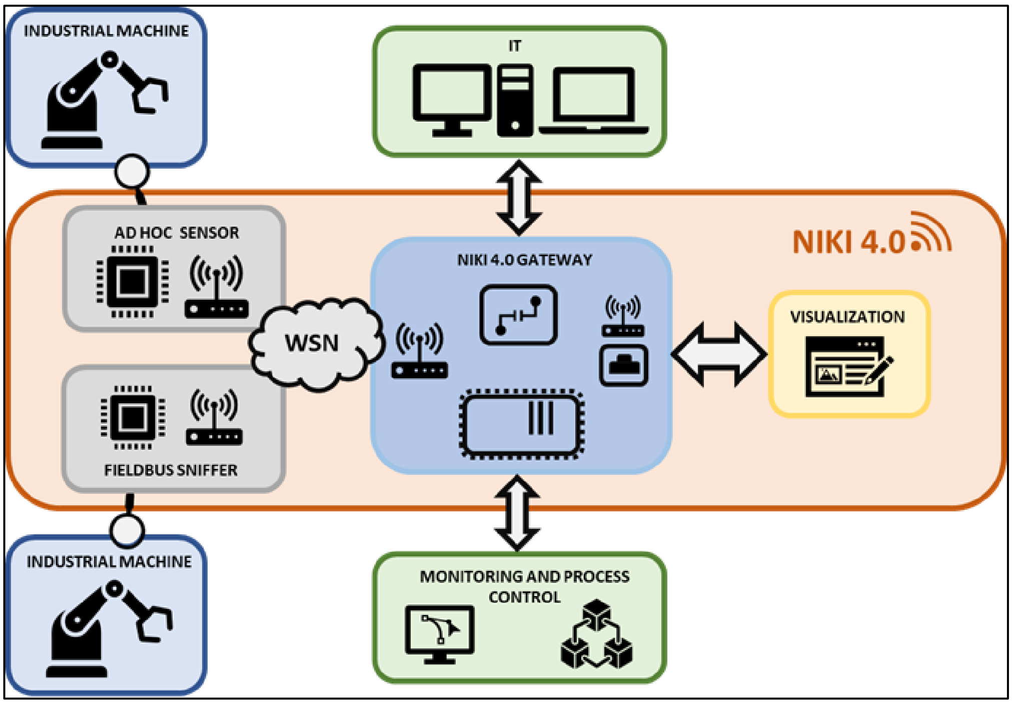


Figure 25. NIKI 4.0.

The toolkit utilizes a three-tier architecture, as depicted in Figure 25. The data acquisition layer encompasses functionalities designed to gather information from sensors, seamlessly integrated with existing industrial machinery, without interrupting their operation. This layer supports the collection of data from various sources, including ad-hoc sensors (e.g., power/environment/ambient sensors, energy flow monitoring sensors) and fieldbus sniffers (e.g., Profibus/Modbus/Interbud sniffers) that can be connected to pre-existing fieldbuses. Acting as the communication and aggregation layer, the NIKI 4.0 gateway facilitates the connection between the sensor nodes and enterprise systems [18]. The designated task involves wirelessly retrieving data from the sensor nodes utilizing a Wireless Sensor Network (WSN). However, alternative approaches such as Ethernet and Wireless Local Area Network (WLAN) can also be employed. Upon collection, the data undergo initial screening and subsequent preprocessing at the gateway. During the preprocessing stage, the data is transformed into OPC Unified Architecture (OPC UA) compliant data models and stored within a database engine for easy access to historical data. This facilitates accessibility for OPC UA clients, enabling them to retrieve the current sensor values, historical data, and past events. Lastly, the visualization layer provides users with a user-friendly interface, presenting the gathered data in a manner that facilitates the identification of potential enhancements and optimizations utilizing Industry 4.0 principles [18].

The primary goal of creating the fieldbus sniffer was to make it possible for SME employees to connect to existing networks without using PLCs [16]. The sniffer in the NIKI4.0 toolkit is built upon the widely adopted Profibus fieldbus system commonly found in manufacturing facilities. RS485 is the primary communication medium within the Profibus network, with RS485 diagnosis interfaces available on Profibus slave devices for monitoring and diagnostic purposes. These interfaces facilitate the collection of various network data, including diagnosis, I/O data, process data, load register data, and context and function invocation data. However, only specific data types such as diagnosis, alarm, status, and I/O data are filtered and extracted from the Profibus packets, which consist of constant and variable length data. The filtered packets' protocol data units (PDUs) are then modeled using the IP Smart Object (IPSO) data model and transmitted via the Wireless Sensor Network (WSN) to the NIKI4.0 gateway.

2.3.7 MTConnect

MTConnect is an open-source standard for communication and data exchange between manufacturing devices and equipment. It provides a uniform way of accessing data from different types of machines and devices, allowing organizations to collect, analyse, and use data from their manufacturing operations [17]. MTConnect enables organizations to improve their operational efficiency, reduce costs, and increase their competitiveness in the global market by providing real-time monitoring of manufacturing devices. This data is without any proprietary format, and is uniform, thus allowing developers and integrators to focus on useful and productive applications, rather than to worry about translation of this data. The data sources may include production equipment, sensor packages, and other hardware.

2.3.7.1 Overview

As mentioned earlier, the goal of MTConnect is to provide a standard way of accessing data from different types of machines and devices. The MTConnect reference architecture consists of the following components [22], see Figure 26 below.

- **Equipment:** These consist of any tangible property, which is used to equip the operations of a manufacturing facility. These might include machine tools, ovens, sensor units, workstations, and software applications etc.
- **Agents:** These are software components that run on manufacturing devices and collect data from them. The agents translate the device-specific data into the MTConnect standard format and make it available for retrieval.
- **Adapters:** These are components that translate data from the MTConnect standard format into a format that can be used by other systems, such as enterprise resource planning (ERP) or manufacturing execution systems (MES).
- **MTConnect Standard:** This is a set of XML schemas and data models that define the structure and format of data that can be exchanged using MTConnect. It includes definitions for equipment status, alarms, and other important manufacturing data.
- **MTConnect Server:** This component is responsible for receiving data from the agents and making it available to other systems. The server acts as a central repository for MTConnect data, providing a uniform way of accessing data from multiple devices.

- **MTConnect Client:** This component is used by other systems to retrieve data from the MTConnect Server. The client can be integrated into existing systems, such as ERP or MES, to allow data to be easily accessed and used.

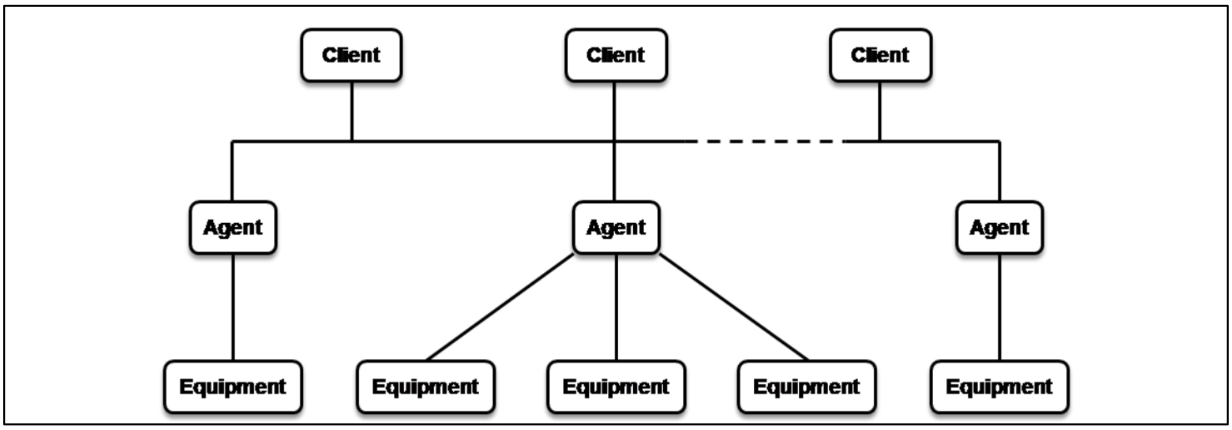


Figure 26. Basic MTConnect Implementation Structure.

The MTConnect reference architecture provides a flexible and scalable solution for data exchange in the manufacturing industry. It enables organizations to collect and use data from their devices, improving their operational efficiency and providing valuable insights into their manufacturing operations (See Figure 26).

2.3.7.2 Main Features

MTConnect, being an open-source standard for communication, offers some great features [22]. The main features of MTConnect include:

- **Data Collection:** MTConnect provides a standard way of collecting data from manufacturing devices, such as CNC machines, robots, and sensors. The data collected by MTConnect agents is translated into a standard format, making it easier to access and analyse.
- **Interoperability:** MTConnect provides a common language for communication between devices, regardless of the manufacturer or model. This enables organizations to integrate data from different devices and use it to improve their operations.
- **Flexibility:** MTConnect is designed to be flexible and scalable, making it suitable for use in a wide range of manufacturing environments. The standard is designed to be easily adaptable to new technologies and changes in the manufacturing landscape.
- **Open-Source:** MTConnect is an open-source standard, which means that it is freely available for organizations to use. This allows organizations to benefit from the collective expertise of the MTConnect community and contribute to its development.
- **Data Security:** MTConnect provides a secure way of exchanging data between devices. The standard includes provisions for secure data transmission and access control, ensuring that sensitive manufacturing data is protected.
- **Real-Time Monitoring:** MTConnect provides real-time monitoring of manufacturing devices, enabling organizations to quickly detect and respond to problems. The real-time nature of the data collected by MTConnect makes it suitable for use in real-time decision-making and control systems.

These are just some of the key features of MTConnect. The standard provides a flexible and scalable solution for data exchange in the manufacturing industry, enabling organizations to improve their operational efficiency, reduce costs, and increase their competitiveness in the global market.

2.3.8 GAIA-X

GAIA-X is an Infrastructure and Data Ecosystem designed to align with European values and standards [6]. Its architecture is driven by this mission and utilizes digital processes and information technology to connect participants in the European digital economy. GAIA-X relies on established standards, open technology, and concepts to promote easy-to-use, quality-assured, and innovative data exchange and services. It also aims to facilitate interoperability and interconnection among participants for both data and services [20].

2.3.8.1 Overview

Digital Sovereignty, specifically Data Sovereignty, is a crucial aspect of GAIA-X's architecture, which aims to establish a digital sovereign ecosystem according to EU standards. The GAIA-X architecture incorporates technological approaches such as federation, self-descriptions and policies, and identity and trusts to support standardized access to GAIA-X, verify engagements, and enable Providers and Consumers to interact. GAIA-X aligns with the European Data Strategy [5], aiming to create a single market for data and provide a secure and easy way for businesses to access high-quality industrial data. The objective is to design and implement a data-sharing architecture and governance mechanism, as well as an EU federation of cloud infrastructure and data services [9].

The GAIA-X architecture (Figure 27) principles are based on the vision and objectives of the architecture and reflect its core values. The principles include Openness and Transparency, promoting open-source licenses and welcoming contributions; Interoperability, enabling all participants to interact in a well-specified way; Federated Systems, specifying a set of standards, frameworks, and legal rules for autonomous providers; and Authenticity and Trust, requiring an identity management system for secure interactions without reliance on a single corporation or government's authority.

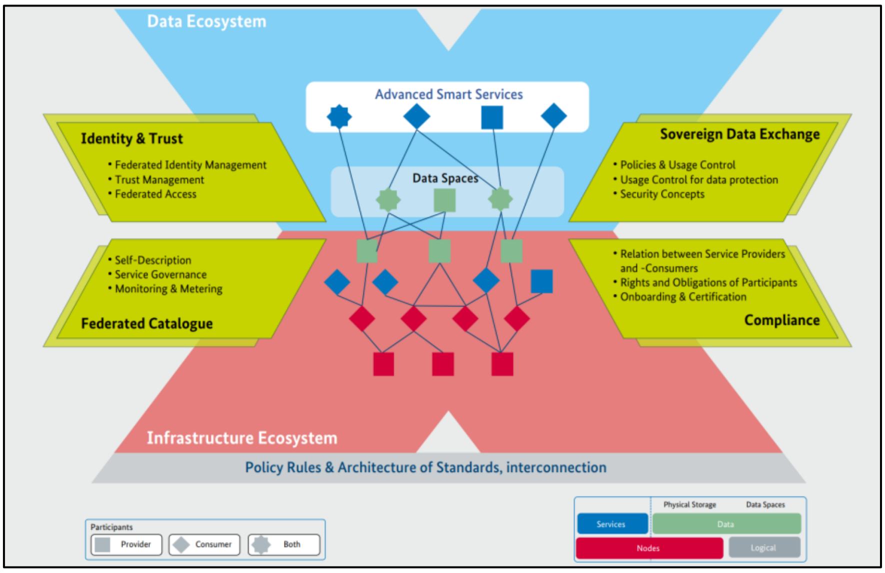


Figure 27. GAIA-X Architecture.

2.3.8.2 Main Features

The GAIA-X ecosystem consists of two ecosystems, the Data Ecosystem and the Infrastructure Ecosystem. The Infrastructure Ecosystem is focused on providing or consuming infrastructure services through the Asset called Node, while the Data Ecosystem focuses on Data Spaces and Advanced Smart Services. The ecosystem is developed in line with the European Data Strategy, and Participants are classified as Providers or Consumers. Services act as the binding element between Providers and Consumers, tying Data and Nodes together. GAIA-X provides technical concepts, functionality for federation and interoperability, and orchestrates the ecosystem, but is not involved in individual transactions between Participants. Federation Services, which include infrastructure services and organizational support, are grouped into four domains.

The concept of **Identity and Trust** is addressed at various levels of the GAIA-X architecture. The following sections provide detailed explanations from different perspectives:

- Federated Identity Management: This refers to the management of identifiers used for authentication purposes.
- Trust Management: This involves establishing trust for all interactions within GAIA-X.
- Federated Access: This specifies how access can be managed in a federated manner.

The **Federated Catalogue (Interoperability)** serves as a repository for Providers' offerings within the ecosystem. The second section of the Catalogue covers the essential architecture elements and their relationships with one another, including self-description, service governance and Monitoring and Metering

To ensure the **sovereignty of data exchange** within the GAIA-X ecosystem, the use of control mechanisms and a comprehensive security concept is implemented. Furthermore, standards for interoperability of data exchange will be established. The following concepts are involved in Policies and Usage Control, Usage Control for data protection and Security Concepts.

Effective **security and data protection** within the GAIA-X ecosystem is reliant on more than just technical solutions. Organizational and governance aspects are also essential. Some of the key elements are the Relationship between service providers and consumers, the Rights and obligations of participants, or Onboarding and certification.

2.3.9 Line Information System Architecture (LISA)

2.3.9.1 Overview

LISA exhibits an event-driven architecture incorporating a prototype-oriented information model and well-defined transformation services. It offers remarkable advantages such as loose coupling, flexibility, and seamless integration with legacy devices. This architectural framework has undergone rigorous evaluations using actual industrial data and has been successfully demonstrated in industrial settings. Furthermore, it is currently being implemented in a prominent automotive company, showcasing its practical applicability and potential for widespread adoption [25].

2.3.9.2 Main Features

LISA employs an Enterprise Service Bus (ESB), which acts as an intermediary for message routing among distributed applications. To ensure loose coupling and avoid point-to-point connections, the ESB must have the capability to support the following Enterprise Integration Patterns (EIPs):

- Message: Information or data is encapsulated within a message, which can then be transmitted over a message bus.
- Messaging: Messages are promptly, reliably, and asynchronously transferred using customizable formats. Messaging operates on an event-based model, where new messages are sent to the message bus.
- Publish-subscribe channel: When a message is transmitted on a publish-subscribe channel, a copy of the message is distributed to each subscriber of the channel.
- Message filter: Incoming messages are evaluated against specific criteria defined by a message filter. If a message fails to meet the filter's requirements, it is discarded.

In the LISA prototype, Apache ActiveMQ is utilized as the ESB. However, any ESB that supports these patterns can be substituted. Figure 28 provides an overview of LISA's communication architecture.

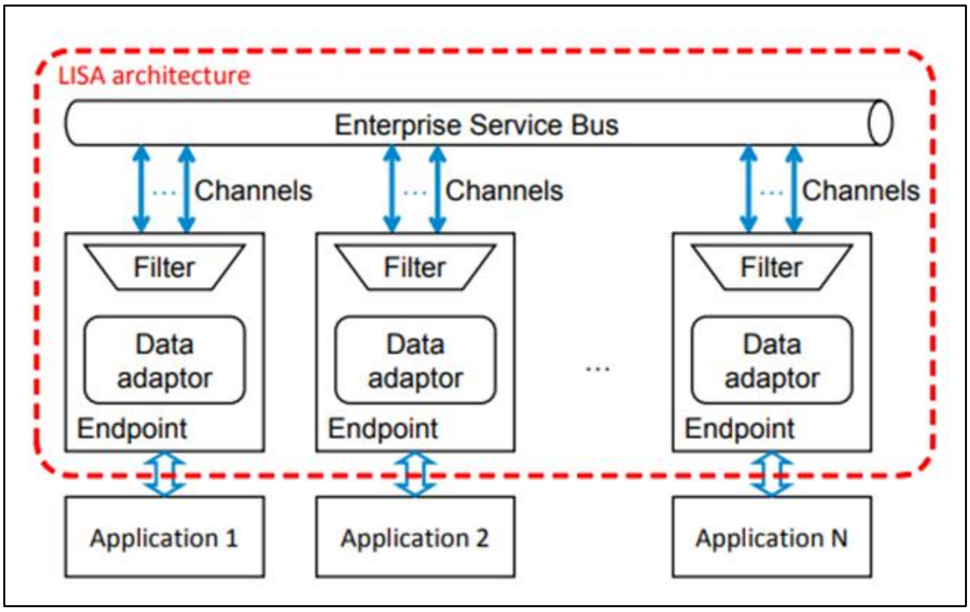


Figure 28. Overview of LISA communication architecture.

Applications (devices, services, external applications) are connected to the ESB (Enterprise Service Bus) via endpoints, which serve the following purposes:

1. Adapting events and information to adhere to the LISA message format.
2. Publishing LISA messages on the appropriate channels within the ESB.
3. Filtering incoming LISA messages received from the ESB.

If an application undergoes modifications, such as hardware replacement, variable renaming, or the addition of new measurements, only its endpoint needs to be updated. No other endpoints or applications require any changes.

The LISA message format is intentionally designed to be simple and impose minimal structure. It consists of a header and a body. The header contains information related to message transmission and routing, while the body consists of an ordered attribute-value map. Values typically consist of primitive data types but can also include lists or maps, allowing for hierarchical structures in LISA messages. The only mandatory attributes in the message body are the event ID and timestamp (t). Beyond that, there are no constraints.

Each plant has a unique system structure, featuring various types of devices, and LISA has the capability to integrate any device at levels 1 and 2. LISA achieves this by allowing users to define events, which may be seen as a drawback. However, this approach offers the advantage of easy modification and extension of events, contributing to the overall flexibility of LISA.

2.3.10 Potential Interest for AIDEAS

During this section, it has analyzed different cutting-edge reference architectures based on the experiences gained by the various members of the AIDEAS consortium. These architectures provide common frameworks and solutions to address challenges in industry and data management. Here, it will summarize the key characteristics of each of them.

- Starting with IIRA, this architecture focuses on developing IIoT solutions. It provides a common framework that enables organizations to integrate and standardize their systems more easily. IIRA aims to reduce development time and costs while improving overall performance and reliability of IIoT solutions. Achieving this requires an environment that allows AIDEAS solutions to interact with industrial equipment, ensuring integration, standardization, scalability, and security.
- On the other hand, RAMI 4.0 allows describing different use cases, standards, and end-user perspectives considering all actors in industrial production. RAMI 4.0 supports different standards across different layers, such as OPC UA in the communication layer. This architecture facilitates exploring different perspectives and ensures interoperability and flexibility in industrial systems.
- The IoT Reference Architecture (ISO/IEC 30141) focuses on optimizing device availability, ensuring data and software integrity, promoting modularity for flexible system configurations, and enabling structured information exchange across interoperable networks. Device availability is measured by network reliability and connectivity, while data and software integrity protect against unauthorized manipulations. Modularity and standardized interfaces increase flexibility and customization capabilities. Additionally, interoperable networks facilitate data transmission and interaction between devices and software services.
- Regarding IMSA, it plays a crucial role throughout the lifecycle of a project. During planning, it helps define project goals and requirements. In the analysis phase, it evaluates existing systems and identifies gaps. In the design phase, it creates a comprehensive plan specifying hardware, software, and interfaces. During implementation, IMSA guides system construction and testing. Finally, in the operation phase, it supports ongoing management, including monitoring, troubleshooting, and maintenance, ensuring efficient and effective system operation.
- IDS is another reference architecture that focuses on data management in industrial contexts. This architecture includes features such as interoperability, data protection, data governance, and identity and access management. Interoperability ensures smooth data exchange between IDS systems. Data protection ensures the security and confidentiality of sensitive information. Data governance ensures responsible and ethical use of data throughout its lifecycle. And identity and access management establish secure and efficient systems for user identification, authentication, and access control.
- The NIKI 4.0 toolkit, while not subject to standards, offers a way to upgrade older machines and make them compatible with Industry 4.0 without altering their structure. This toolkit, available on GitHub as open-source, allows retro-fitting old machines and bringing them closer to the Industry 4.0 paradigm. NIKI 4.0 utilizes well-known protocols like OPC UA and has a three-tier structure similar to other architectures. It is particularly useful in the Smart Retrofit area, providing a solid foundation for integrating new technologies into legacy systems.
- MTConnect is an architecture that provides a standardized way to access and collect data from manufacturing devices. This data can be used for AI and machine learning applications. The data collected by MTConnect agents can serve as input for AI and ML algorithms, enabling

pattern identification, failure prediction, or production program optimization. AI and ML can also be integrated into the MTConnect reference architecture through AI-driven adapters.
- Lastly, GAIA-X focuses on interoperability and promotes open standards and technologies to facilitate reliable and innovative data and service exchange among European participants. This reference architecture aims to connect all participants within Europe, establishing user-friendly and quality-assured data and service exchange concepts and standards.

In summary, the reference architectures analyzed in this section provide frameworks and solutions to address challenges in industry and data management. These architectures foster integration, standardization, interoperability, and security, enabling organizations to enhance the performance and efficiency of their IIoT systems and make the most of data collected in industrial environments. They promote collaboration among different industry actors and offer tools and standards to drive digital transformation and efficiency in production.

3. Digital Product Passport

The European Commission has launched a Digital Product Passport (DPP) initiative to help consumers and businesses access reliable and standardized information about the environmental impact, safety, and authenticity of products[20]. The concept of a 'product passport' as defined by the European Commission (EC) refers to a specific dataset associated with a product. This dataset can be accessed electronically via a data carrier to facilitate the electronic registration, processing, and sharing of product-related information among supply chain businesses, authorities, and consumers. The Digital Product Passport (DPP) serves as a valuable resource by providing details regarding the product's origin, composition, repair and disassembly options, as well as guidance on recycling or proper disposal methods at the end of its lifecycle. This information plays a crucial role in promoting circular economy strategies such as predictive maintenance, repair, remanufacturing, and recycling. Additionally, it serves as a means to inform consumers and other stakeholders about the sustainability characteristics of products and materials [21]. The initiative aims to create a "digital twin" of physical products, providing a comprehensive and standardized set of information that can be easily accessed and shared. This DPP will include information about the product's environmental impact, such as its carbon footprint, energy consumption, and resource use. It will also include information about the product's safety and regulatory compliance, such as its compliance with EU safety regulations and standards. Additionally, it will include information about the product's origin and authenticity, providing consumers with greater transparency and confidence in the products they purchase. This initiative is part of the European Union's broader efforts to create a circular economy, where products are designed to be reused, repaired, and recycled. By providing consumers and businesses with reliable and standardized information about the products they purchase, the initiative aims to promote sustainable consumption and production practices [4].

The DPP initiative seeks to improve product transparency and sustainability through the use of digital technologies, being a compliance tool when required by government regulations, as in the case of the new EU Battery Regulation, this new "cradle to grave" regulation on batteries will require the adoption of a substantial amount of more detailed rules (secondary legislation) between 2024 and 2028 to be fully functional[22]. It aims to create an online database containing detailed information on the composition, lifetime, carbon footprint and other relevant aspects of products, such as batteries, to increase collection targets, reuse and recycling rates.

To implement a product passport for a product, the cooperation of stakeholders throughout the supply chain is necessary. To ensure the success of the product passport and fulfil the above-mentioned benefits, it is important that no product passport silos are formed, but that the entire industry participates in a common technical solution. Only an industry-wide common solution allows the desired network effects to be achieved because with the involvement of the actors in

[20] https://medium.com/@susi.guth/the-digital-product-passport-and-its-technical-implementation-efdd09a4ed75

[21] https://circulareconomy.europa.eu/platform/sites/default/files/cisl_digital_products_passport_report_v6.pdf

[22] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7588

the supply chain, alignment of objectives and increased functionality of the solution is achieved. All actors and data needed to meet the requirements of the product passport must be identified. This can be done, for example, with expert interviews, surveys and industry meetings. For the case of the project, the first phase of the project already starts to collect information on these requirements, starting with the definition of data types to be used in each use case of the different pilots. Therefore, the DPP enables end-to-end product traceability, guaranteeing the monitoring of data and product status at any time. Therefore, the actors can themselves determine the storage location of their product data records, thus creating a decentralized product data space, i.e. a product passport stored in distributed data warehouses. The advantages of having decentralized technology:

- **Data quality**. The correctness of the data can be proven by linked electronic certificates. These electronic certificates serve as proof of data integrity and accuracy, and their linkage enables transparent traceability of data throughout the supply chain. In addition, these certificates can be used as a mechanism to ensure the authenticity and confidentiality of the information and can be used as evidence in case of disputes or litigation.
- **Decentralized storage and access control**. Since each actor stores its signed data sheets in a decentralized manner, it also can control access to them. In this way, the actor can ensure that competitors do not access any company secrets, but that only an auditor, a client or a ministry can see the data concerning them. The access control mechanism can also be based on DID and verifiable credentials, e.g., the Federal Environment Agency needs to show its credentials to access product passport data.
- **End-to-end verifiability**. The economic operator placing the battery on the market should prove that the battery passport data is correct, complete and up to date. Decentralized technologies make it possible to ensure end-to-end verifiability of product data throughout the value chain.
- **Real-time updating**. If information about a product changes, the proposed concept makes it possible to update it electronically and display it to the user in real-time. This applies to instructions for use, disassembly instructions, package inserts and any other information in the product passport.
- **Inclusivity**. The decentralized concept presented allows all companies to participate in the product passport. When the product passport is introduced, open-source solutions will already be available to manage the decentralized identifiers. The fact that all economic actors can participate in the digital product passport is also necessary to ensure a critical mass of participating companies; network effects can also be exploited in this way.
- **Flexibility**. Using a decentralized public key infrastructure, which is the basis for decentralized identifiers, actors are not directly integrated, but against a decentralized trust anchor. This way, the actors and attributes defining the product passport can be flexibly extended.

4. Context of AIDEAS

4.1 Product Lifecycle Management and SCOR model

Product Lifecycle Management (PLM) is a holistic approach to managing the entire lifecycle of a product, from conception, design and manufacture to service and disposal [24]. The components of PLM are people, processes, data and technology. These interconnected components work together to manage all aspects of a product's lifecycle. The people or agents involved in the product lifecycle can be designers, manufacturers, suppliers, customers and service providers. Processes include design reviews, change management procedures, quality control checks and supply chain management activities that ensure efficient operations. Data includes all information related to a product, such as specifications, bills of materials (BOMs) or engineering drawings, which are managed in a centralised database for easy access by all stakeholders. Technology includes software tools such as computer-aided design (CAD), simulation software to test designs before production begins; enterprise resource planning (ERP) systems to manage production schedules; customer relationship management (CRM) systems to track customer feedback; and analytics tools to monitor performance metrics throughout the lifecycle.

The length of a product's life cycle varies depending on the type, but the same supply chain management principles can apply universally. For short-lived commercial products, it's crucial to optimize design and manufacturing for efficiency and cost reduction. In contrast, industrial products with longer life cycles require consideration of sustainability and corporate social responsibility due to their significant environmental and societal impact. The application of the Supply Chain Operations Reference (SCOR) model in supply chain management can help improve the efficiency and quality of the supply chain, which translates into benefits for both companies and end consumers.

The manufacturing phase is critical in the product lifecycle, during this phase, the focus is on planning and executing the production process efficiently to meet customer demand while maintaining quality standards. The manufacturing phase includes several activities, such as manufacturing process design, production planning, material procurement, assembly, testing and quality control.

- **Manufacturing process** design involves developing the manufacturing processes and selecting the appropriate equipment to manufacture the product efficiently.
- **Production planning** involves scheduling production runs and allocating resources such as labour, materials and equipment to meet production targets.
- **Materials procurement** involves obtaining raw materials from suppliers and managing inventory levels to ensure there are no shortages or excesses.
- **Assembly** consists of assembling the various components of the product according to design specifications.
- **Testing** consists of verifying that the product meets all quality standards and performance requirements.
- **Quality control** consists of monitoring all aspects of the manufacturing process to ensure that the products meet customer expectations.

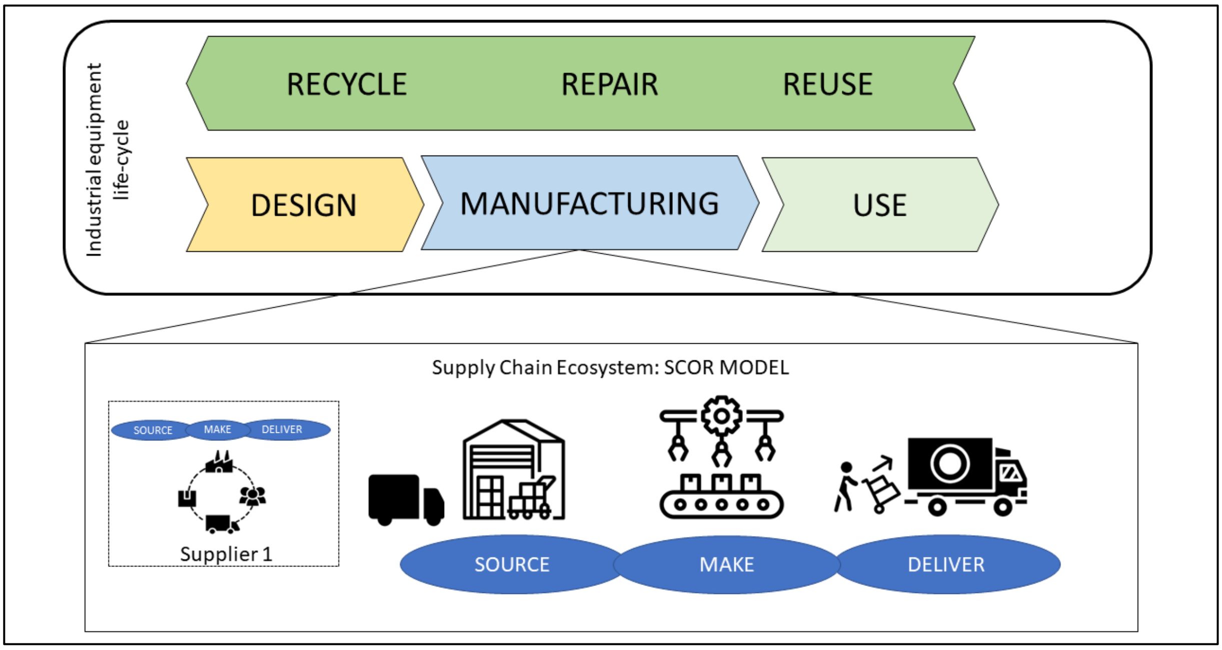


Figure 29. Supply chain ecosystem within the manufacturing phase.

Overall, the manufacturing phase is critical to ensure that products are manufactured efficiently at high-quality levels to meet customer demand. Although the SCOR model focuses on the manufacturing phase as shown in Figure 29 it also considers other aspects with a more global view of the supply chain. As is well known, the product, or in this case machine, goes through the entire supply chain from suppliers to manufacturers and ends at the customer's site. Finally, after using the machine at the customer's site, this machine can be returned to the company's site to give it a second life. This path is known as a closed supply chain; different operations are required at each machine state. The SCOR model can be connected to the product life cycle through supply chain management at each life cycle stage: design, manufacture, use and recycling.

- In the **design phase** of the life cycle, the application of the SCOR model can help establish the supply chain requirements needed to design the product, identify the suppliers of materials and components, and establish the specifications of the manufacturing process based on the characteristics established in the design phase. On the supply chain side, the SCOR model facilitates the planning and design of subsequent operations and can help optimize material and component procurement costs, improve product quality, and reduce production time.
- In the **manufacturing phase,** the application of the SCOR model helps to optimize production and supply chain efficiency. Production planning and supply chain management in the SCOR model helps to reduce production time, minimize production costs, and improve product quality. In this phase, the optimization in distribution operations involves the management of different data such as transportation availability, customer lead time, logistics unit and many more data.
- In the **use phase**, the application of the SCOR model can help to improve customer satisfaction and service quality. Customer service processes in the SCOR model can help manage service requests and repair efficiently. In this case, machine quality is an aspect to be considered, monitoring and optimizing environmental conditions.
- In the **recycling phase** of the life cycle, the application of the SCOR model can help to improve waste management efficiency and sustainability. Waste management planning and materials

management in the SCOR model can help recover end-of-life materials and product components, reduce disposal costs and minimize environmental impact.

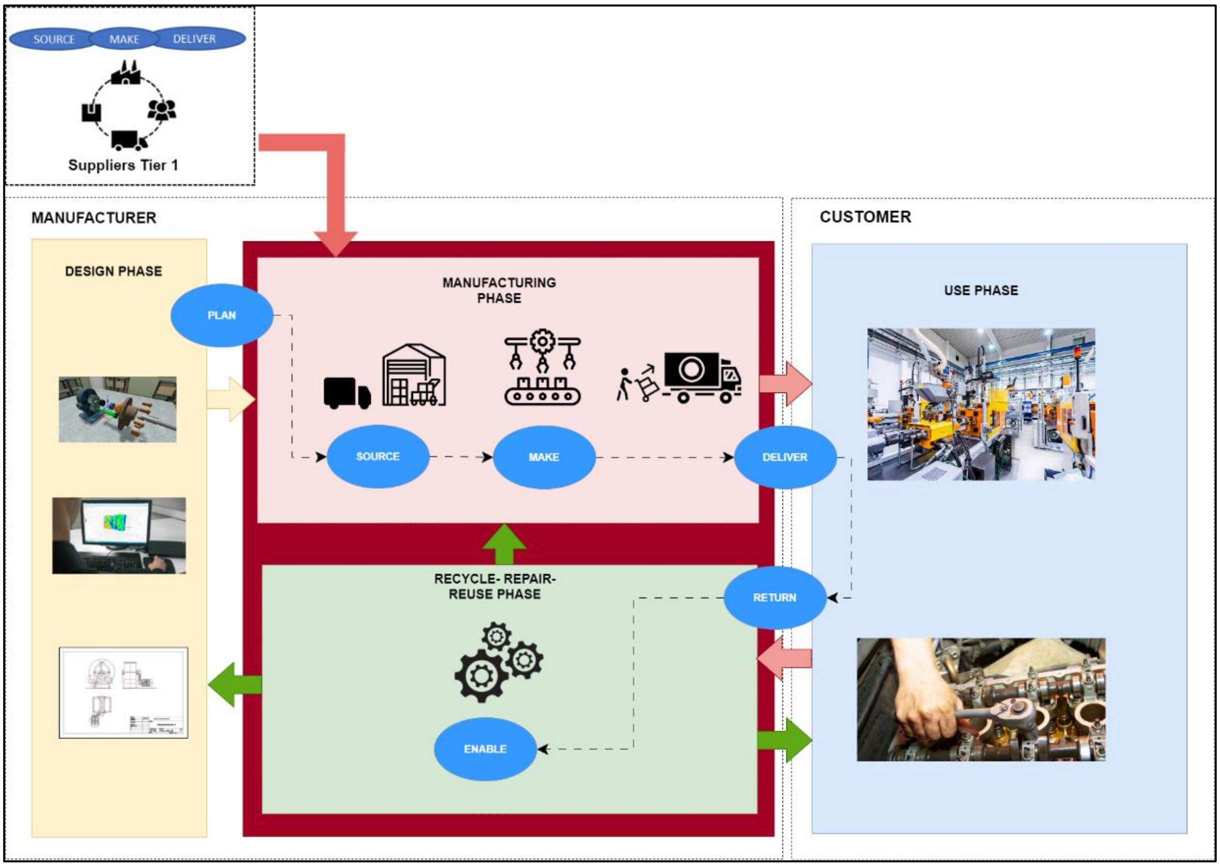


Figure 30. SCOR model deployed in all phases of the machine lifecycle.

All the activities represented in Figure 30 above, connected to each other and found within the entire supply chain, associated with the different phases and nodes of the supply network, are explained as follows:

- **Plan:** Planning processes are designed to help companies make strategic and tactical decisions regarding their supply chain operations. These processes are essential to ensure that resources are allocated and utilized efficiently and that the company can meet customer demand effectively. This phase is crucial to the efficiency and effectiveness of the supply chain, as decisions made in this phase will significantly impact supply chain management in the future.
- **Source:** These processes describe the ordering (or scheduling of deliveries) and receipt of products and services. Source processes comprise the issuing of purchase orders or scheduling

of deliveries, receipt, validation and storage of materials and acceptance of the invoice from the supplier.
- **Make:** These are the processes related to the conversion of materials or the creation of the contents of a service. Conversion is understood as more than just producing, it is assembling, repairing, maintaining, recycling, etc.
- **Deliver:** These are associated with creating, maintaining, and delivering customer orders. It covers the reception, validation, and creation of orders, scheduling the delivery order, pick, pack and shipment and invoicing the customer.
- **Return:** Return processes are those that take place when a product is returned to the supply chain. These processes may include identifying the need for the return, scheduling the return, and loading and receiving the returned product. It is important to note that Return processes refer specifically to the return of a product or machine to the point of origin, whether it is to the manufacturer, distributor or retailer. Return processes are directly related to the product use phase. At this stage, products may be returned to the supply chain due to quality issues, defects, changes in customer requirements or other reasons.
- **Enable:** They are associated with supply chain management. It includes business rules management, performance measurement, information management, resource and facilities management, risk management, legal aspects, etc.

In summary, the application of the SCOR model helps to understand the main operations that take place along the supply chain. These operations use different information tools, such as an ERP, which manages different data depending on the status and location of the machine, so a connection between the data of the different phases is necessary.

4.2 AIDEAS Solutions Suites

The solutions of AIDEAS project are focused on optimizing all phases of the life cycle through which the machines pass, which is why they are grouped into four suites. The objective is to cover each phase of the life cycle with a series of AI tools with different functionalities and handling different data. The four suites are:

- **Industrial Equipment Design Suite:** This suite integrates AI technologies with CAD/CAM/CAE systems to optimize the design of structural components, mechanisms, and control elements of industrial equipment.
- **Industrial Equipment Manufacturing Suite:** This suite employs AI technologies to streamline the selection and procurement of purchased components for industrial equipment, optimize manufacturing processes for parts, sequence operations, ensure quality control, and enable customization.
- **Industrial Equipment Use:** This suite enhances the value for industrial equipment users by leveraging AI technologies. It provides advanced support for installation, initial calibration, production processes, quality assurance, and predictive maintenance, enabling optimal working conditions.
- **Industrial Equipment Repair-Reuse-Recycle Suite:** This suite utilizes AI technologies to extend the lifespan of machines through prescriptive maintenance (Repair). It also facilitates the transformation of machines for a second life through smart retrofitting (Reuse) and identifies sustainable end-of-life options (Recycle).

The type of information varies in each of the suites, this variability poses a significant challenge in achieving interoperability and seamless data exchange between different suites within an organization. Without a cohesive architecture, the disparate suites struggle to communicate effectively, hindering data flow and integration. Here appears one of the major needs to be covered by this architecture and that is the introduction of a platform that ensures that the data can last throughout the suites so that it can be used in any type of system. This platform must therefore focus on meeting four needs:

- **Openness and transparency:** Technology specifications, architecture and documentation must be accessible to participants in the production chain. Technology choices will be made to encourage the distribution of collaboratively created artefacts under open-source licences; considering that these technologies are evolving and are open to future innovations and standards.
- **Interoperability:** All participants within the reference architecture will be able to interact with each other in a well-defined way. Therefore, the AIDEAS solutions will describe the technical means to achieve this, using different standards for implementation, communication and data management.
- **Federated systems:** The communication between entities will be governed by federated systems consisting of autonomous providers. These providers will adhere to a defined set of standards, frameworks, and legal rules, ensuring a cohesive and harmonized approach.
- **Authenticity and trust:** To establish a secure digital ecosystem, an identity management system incorporating mutual authentication, selective disclosure, and trust revocation is essential. This system will promote trust and ensure the authenticity of interactions within the ecosystem.

4.3 Machine Passport

Transferring the concept of DPP to the project, it refers to any type of product in which a system is to be implemented to manage the product from start to finish, however, the product for this project is based on industrial equipment or machines. Thus, **The Machine Passport (MP)** solution arises from this concept. MP, therefore, refers to a solution that provides detailed information about a machine or equipment used in the production of goods. Just as a traditional passport identifies and provides personal data, this digital document identifies and provides specific details about the machine. The MP aims to facilitate the traceability, management and control of machines used in the manufacture of products throughout the entire life cycle of the machines and, with this information, to be able to identify the most difficult phases.

The operation of the MP is based on the collection and storage of relevant information about the machine. This information may include data such as the unique identification of the machine, its maintenance history, dates of manufacture, technical specifications, components used and any other relevant information. The record is kept up to date throughout the life of the machine and can be accessed electronically for queries and updates. To support the operation of the Machine Passport, several associated technologies are used. This may include the use of unique identification systems such as barcodes, Radio Frequency Identification (RFID) tags or QR codes to link the machine to its electronic record. In addition, data management solutions and centralised databases can be used to store and manage MP information. These technologies allow fast and secure access to information, facilitating traceability and decision-making in the management of the production machinery. By identifying the point at which a machine's performance declines, a plan can be made to improve its design, manufacture or use based on accurate and reliable information.

In each phase of the life cycle, different types of data are handled, which are handled by different profiles related to the phase in which the machine is. For example, in the design phase, data and documents related to the design of the machine are handled, within this phase there will be machine design engineers in charge of the creation and simulation of the machine. This type of data is different from the manufacturing phase since in this phase it is not important to know the dynamic parameters of the machine, but to how it is manufactured based on the specifications of the materials and components.

Overall, the MP serves as a comprehensive repository of information throughout the entire lifecycle of a machine. It enables effective data management, facilitates decision-making processes, enhances traceability and fosters continuous improvement in machine design, manufacturing and operations. By harnessing accurate and relevant data, companies can optimise their supply chain management, reduce costs, ensure sustainability and meet corporate social responsibilities.

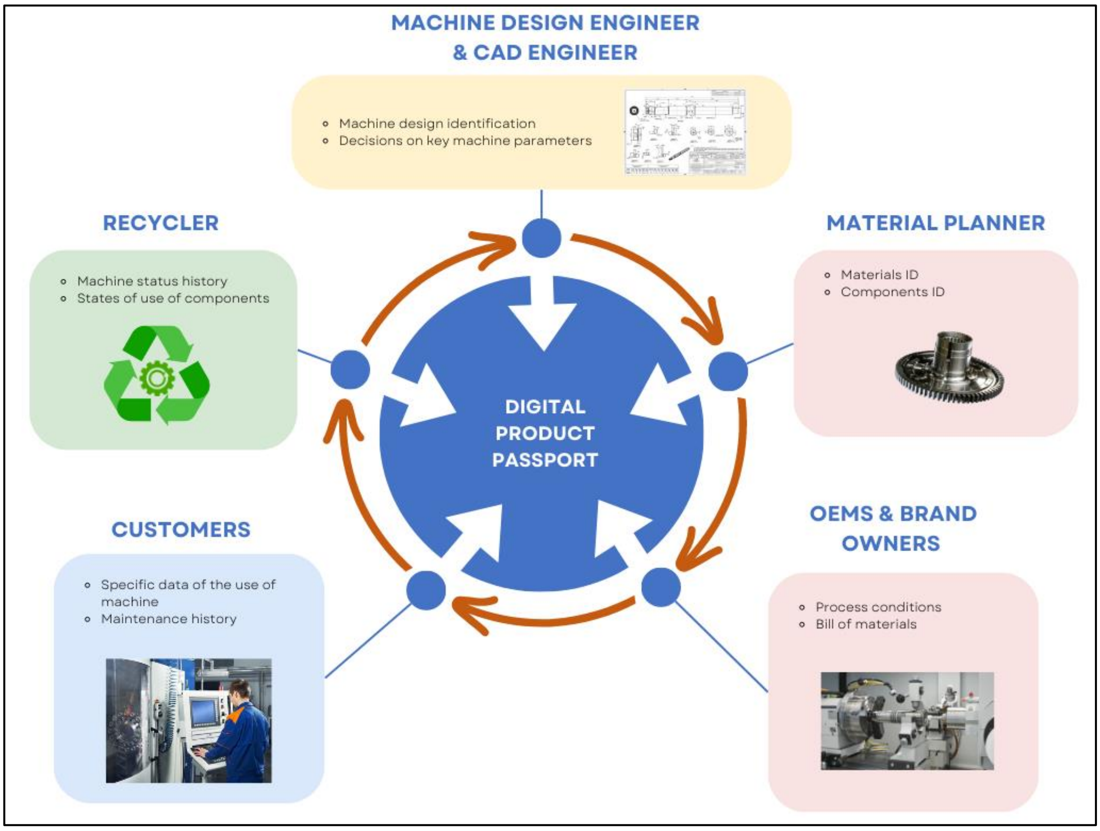


Figure 31**.** Connection between product data via the DPP.

The relevant information in each phase is managed by different stakeholders belonging to different phases of the product life cycle. The stakeholders shown in Figure 31 are listed below, and the type of activities and data they handle are described.

Machine design engineer & cad engineer. A machine design engineer is responsible for designing machines and mechanical systems to meet customer or company requirements. Activities may include:

- Research and develop design solutions to meet project requirements.
- Create and review CAD models and drawings to refine the design and ensure that the parameters match the dynamic and physical requirements of the machine.
- Perform simulations and testing on prototypes to verify design performance and reliability.
- Collaborate with other engineers and technical professionals to ensure that the design meets project requirements.

Material planner. A material planner is responsible for ensuring that the necessary materials are available at the right time and place to meet project requirements. Activities may include:

- Creating and maintaining short- and long-term production plans to ensure material availability.
- Analyze market trends and customer demand to adjust production plans as needed.
- Manage inventory and material stocks to maintain them at optimal levels.
- Collaborate with suppliers and other departments to ensure materials are delivered on time and meet quality requirements.

OEMs & brand owners. OEMs and brand owners are companies that design and manufacture products for sale under their brand or for other manufacturers. Activities may include:

- Development of manufacturing and supply chain management plans to ensure the availability of materials and on-time delivery of finished machines.
- Monitor product quality and performance to ensure customer satisfaction.
- Collaborate with suppliers, distributors and other business partners to ensure machine success.

Customers. Customers are the end users of companies' products and services. Activities may include:

- Providing feedback and criticism on machines and services to help companies improve quality and performance.
- Request technical support or customer service in case of problems or questions related to the machine or service.

Recycler. A recycler collects and processes recyclable materials for reuse in producing new machines. Activities may include:

- Collecting recyclable materials from households, businesses, and other locations.
- Transporting the materials to a recycling facility for processing.
- Follow environmental regulations and standards to ensure compliance and sustainability of the recycling process.
- Promote awareness of the importance of recycling and educate the public on how to participate in sustainable recycling practices.
- Develop and maintain relationships with other recyclers, manufacturers and companies to identify opportunities for business and collaboration in recycling and producing new sustainable products.

In conclusion, MP serves as a solution to the challenge of interoperability between different suites and their respective data types, fosters a unified data ecosystem, streamlines workflows, and improves operational efficiency. MP is emerging as a critical tool to drive data-driven decision-making across the organisation, enabling seamless integration and utilisation of data across multiple systems.

5. AIDEAS Reference Architecture

Industrial Systems are often represented by common, typical, or essential features grouped in several architecture patterns. The primary goal of an RA is to improve the efficiency, reliability, and safety of industrial systems by providing a standardized approach to system design and operation. An RA typically covers various aspects of industrial systems, such as hardware and software architecture, communication protocols, data management, and security.

As part of the twin green & digital transition promoted by the EU, the AIDEAS Reference Architecture (AIDEAS-RA) abstracts and simplifies the core concepts, and functionalities of the management of the entire life cycle of a product and the use of digital Machine Passports enabling the Circular Economy Business Model in the EU countries. By gathering requirements derived from different uses cases scopes described in WP1, this document aims to unify the different solutions architecture in the AIDEAS RA.

5.1 Methodology

To build the reference architecture, three fundamental phases are defined. First, a conceptual definition of the fundamental theoretical bases for the construction of architecture, such as pattern architecture, data security zones, functional domains, etc. Subsequently, the first point of view is identified, which will be the basis for the following points of view, as it defines the parties involved throughout the entire life cycle (Business viewpoint). Finally, the use, functional and implementation viewpoints are developed for each solution.

5.1.1 Architecture Pattern

AIDEAS RA follows the well-established three-tier architecture pattern. This pattern comprises edge, platform and enterprise tiers.

- **Edge Tier**: This layer includes devices and sensors that collect data from the physical world. The edge layer is responsible for acquiring and processing data locally, filtering and pre-processing it, and sending it to the next layer. The Edge Tier is usually located closed to the IoT devices.
- **Platform/Data Tier**: This layer is the middleware layer that manages data processing and communication between edge devices and the application layer. The platform tier can also provide services such as security, authentication, and data validation. To satisfy data security requirements in some scenarios, the platform tier can be unfolded into Fog Tier and Cloud Tier:
- Fog Tier refers to the local deployment of AIDEAS. This is a decentralized computing infrastructure that brings computation and data storage closer to the edge of the network, closer to the sources of data generation and owned by AIDEAS participants.
- Cloud Tier refers to the remote deployment of AIDEAS. This is the centralized infrastructure to store, manage, and process data and is commonly managed by an AIDEAS enabler.
- **Enterprise Tier**: This layer is the topmost layer and is responsible for the application logic, user interface, and presentation of data to end-users. It includes software applications and

services that consume data from the platform layer and provides business insights and decision-making capabilities to users.

AIDEAS solution suite will serve as the application layer, which is positioned at the top layer of a software system or architecture. It is responsible for providing user interfaces, business logic and application-specific functionality. The data layer, which is a foundational layer within the overall software architecture. The data layer is responsible for governing and storing data, supporting a wide range of aspects of industrial data management (data access management, data discovery, data interoperability, etc.). The AIDEAS solution suite will be built on top of the MP solution, the implemented data layer, which means that it will leverage the data layer to provide its functionality. Therefore, the suite will interact with and use the data stored in the MP to deliver its services or solutions (See Figure 32).

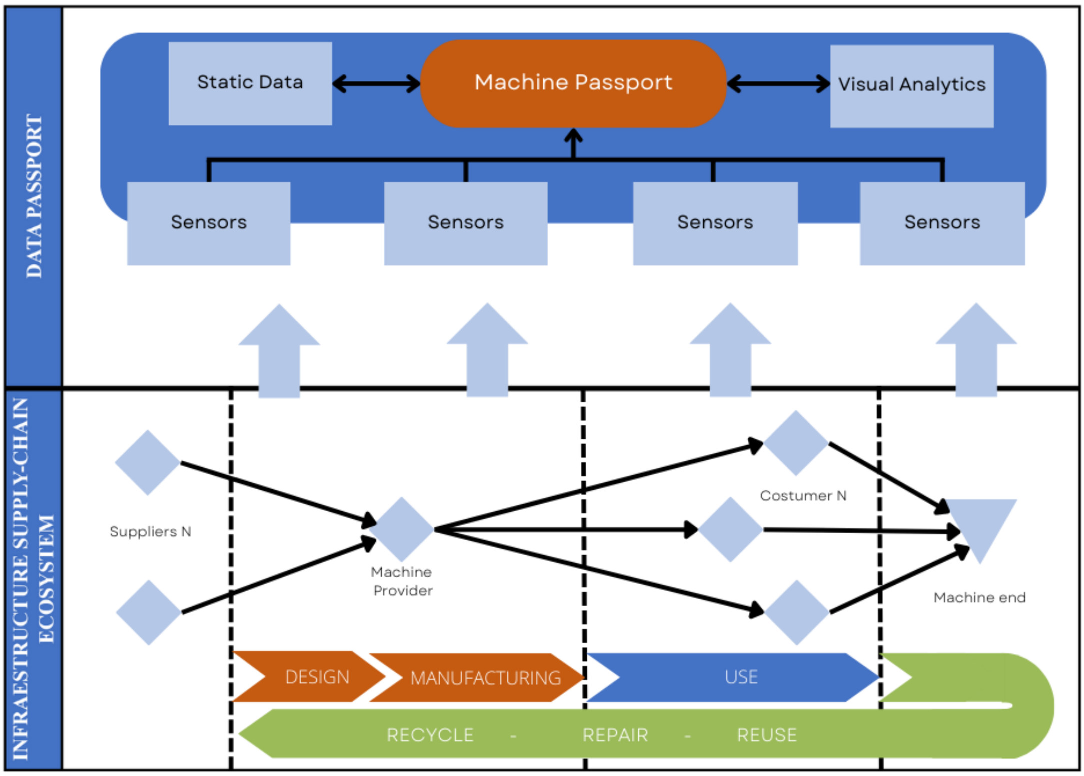


Figure 32. AIDEAS Supply Chain Architecture.

5.1.2 Security Zones

Systematic collection and integration of data sources across the entire product lifecycle is pivotal for becoming competitive in dynamic industrial ecosystems. Data sharing with companies beyond organizational boundaries is a powerful enabler for boosting business outcomes. However, exposing sensitive information might be harmful to corporations from legal or commercial point of views. To strike a balance between providing secure and controlled access to sensitive information or operations within the enterprise while offering more accessible and open services to external entities, AIDEAS RA differentiates between a "Restricted Enterprise Zone" and a "Public Zone" representing two contrasting areas within an enterprise network or system:

A Restricted Enterprise Zone refers to a designated area within an enterprise network that is tightly controlled and restricted to authorized personnel or entities. This zone typically contains sensitive data, critical systems, or confidential operations that require strict access controls and security measures.

A Public Zone, in contrast, refers to an area within an enterprise network that is openly accessible to both authorized users within the organization and external entities, such as customers, partners, or the public. This zone is typically designed to provide services, information, or resources to a wide range of users. Even though the security measures are relaxed when accessing systems in the public zone, mitigation of information leaks must be guaranteed. The specific implementation and configuration of these zones will depend on the organization's security requirements, industry regulations, and the nature of their business operations.

5.1.3 Functional Domains

A functional domain refers to a logical grouping of industrial system functions that work together to achieve a specific set of goals or objectives. Functional domains in internet industry systems can vary depending on the specific system. AIDEAS RA defines four main functional domains in industrial systems, which are:

- **Edge Domain:** This domain refers to the layer of computing infrastructure that is located at the edge of the network, closer to the devices and sensors that generate data. The edge domain serves as an intermediary layer between the devices and the other domains. This functional domain will be located under the Edge Tier.
- **Information Domain:** This domain is responsible for managing the information flow within the system. It includes functions related to data acquisition, data processing, data storage, and data communication. From AIDEAS perspective, the complex data management scenario might require additional data-related functionalities such as data discoverability or data access management. This functional domain will typically be located under the Platform/Data Tier,
- **Application Domain:** This domain is responsible for providing specific application services to the system. It includes functions related to implementing specific industrial applications, such as process control, condition monitoring, and predictive maintenance.
- **Business Domain:** This domain is responsible for managing the business processes of the system. It includes functions related to planning, scheduling, resource management, and performance monitoring.

5.1.4 Generic Scenario

A traditional IoT application goal is to monitor the status of Industrial things/devices to ensure the correct functioning and in case of deviation, apply corrective actions. A possible implementation of this solution following the AIDEAS RA would contain several subsystems spread across different domains. The functional decomposition of the system includes:

Within the Edge Domain, the following modules can coexist:

- **Device Gateway:** The Device Gateway subsystem is responsible for collecting and preprocessing device data and preparing it for transfer to the Platform/Data Tier functions.

Within the information Domain, the following modules can coexist:

- **Data storage subsystems:** These subsystems handle the storage of data that will eventually be used by AIDEAS solutions. Depending on the level of data confidentiality, the data can be stored in either a restricted Enterprise zone with strict network policies or a more relaxed environment known as the public zone. This separation allows for finer control over sensitive data.
- **Data management subsystems:** These subsystems support various functionalities related to data management, such as data access monitoring and data catalogues.

Within the Application Domain, the following modules can coexist:

- **Solutions/Applications:** These encompass a combination of microservices, interfaces, ML algorithms, and databases that support specific business logic.

Within the Business Domain, the following modules can coexist to enable end-to-end operations of the industrial internet of things systems:

- **IdP**: An Identity Provider (IdP) is a system responsible for creating, storing, and managing digital identities. The IdP can authenticate users directly or provide authentication services to third-party service providers such as apps, websites, or other digital services.

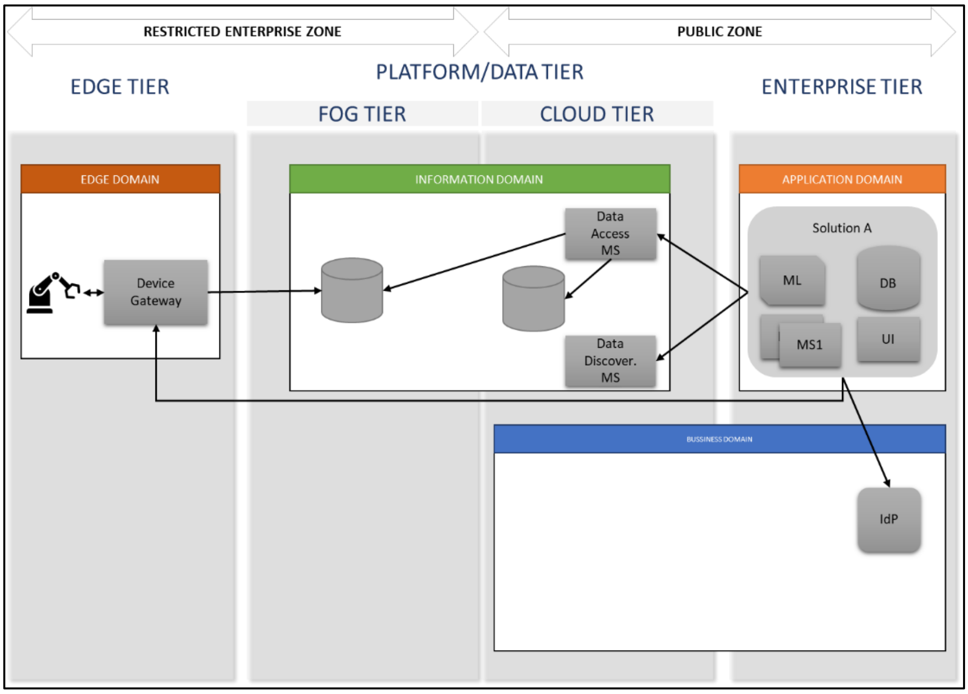


Figure 33. Generic Scenario.

5.1.5 Viewpoints

After the contextualization of the AIDEAS project, the investigation of different European projects and the analysis of different reference architectures, the following section will provide guidance for the development of the system architectures, the solution, and the different possible applications. In this process, we seek to realize common and coherent definitions of a common design pattern and vocabulary by focusing on discussing the implementation specifications of the solutions. For this purpose, we will be inspired by the Industrial Internet Reference Architecture (IIRA). This is because it provides us with a generic architecture description and representation at a high level of abstraction within industry applicability.

The basis of the IIRA methodology is the conceptualization of the system called viewpoints, which allows different architects, developers, and engineers to solve different design problems. For this purpose, the design is divided into four phases that allow defining the different viewpoints of the stakeholders, providing a certain order that allows reflecting a pattern of interactions between them, since the decisions of a higher-level viewpoint impose requirements on the viewpoints below it [10].

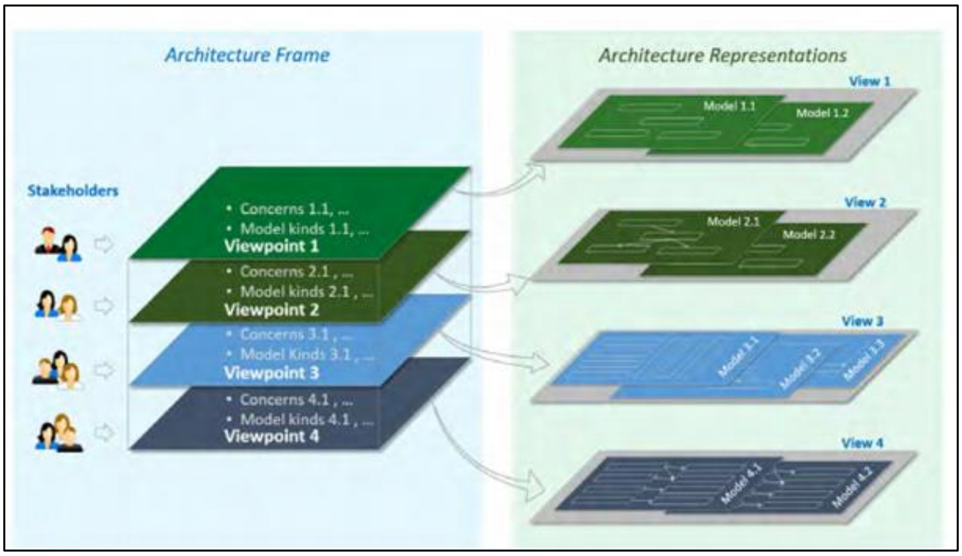


Figure 34. IIRA Architecture Framework [10]

This AIDEAS approach reflects this methodology, basing the definition of solutions on these views in an iterative approach, detailed below. These points of view are divided into four (Business viewpoint, Usage viewpoint, Functional viewpoint and Implementation viewpoint). The AIDEAS-RA will incorporate the relevant perspectives of the smart manufacturing process that will be structured around the four viewpoints seen to provide a framework for thinking iteratively through architecture issues that may arise during its conception. According to the IIRA, which focuses on capabilities from a software and business process perspective, the main characteristics of the viewpoints that will drive the improvement and implementation of the AIDEAS Framework are summarized as follows:

- **The business viewpoint**, is responsible for identifying the parties involved in the development, deployment, and operation of the solutions, including their business goals and objectives. On the other hand, the roles of the parties involved will be defined, considering the data. This will allow us to know which individuals can interact directly with the machine Passport.

- **The usage viewpoint** is dedicated to specifying how the solutions are used. This is illustrated through sequences of activities performed by human actors and/or logical components, such as system components. On the other hand, we have added the development of the interfaces with which the different actors can interact.
- **The functional viewpoint** oversees describing the functionalities of the solutions. To achieve this, the functional components that are part of the solutions are illustrated, together with their interfaces and interactions. Interactions with external logic modules, such as external subsystems or other AIDEAS solutions, are also included.
- **The implementation viewpoint** covers the technologies used to implement the functional components of the solutions. Defining their requirements and technological architecture.

Considering the distribution of these viewpoints, it can be observed that there is a general pattern of interaction between them. Thus, decisions from a higher point of view impose requirements on lower points of view. On the other hand, decisions made from a lower point of view, or definition of requirements, generate revisions in the points of view above it.

5.2 AIDEAS Business Viewpoint

The Business viewpoint addresses business-oriented challenges, which focus on everything that brings value to the business, from business strategies to financial concerns to the expected return on investment. These stakeholders provide the business vision and are decision-makers covering key stakeholders, activities, actions, information flow and interactions between processes. Essentially, this view outlines the key actors, objectives and core capabilities that drive this view. As explained in the sections below, the AIDEAS business viewpoint provides a portrayal of business operations that can be applied to multiple companies, identifying shared processes and potential opportunities for information sharing and reuse.

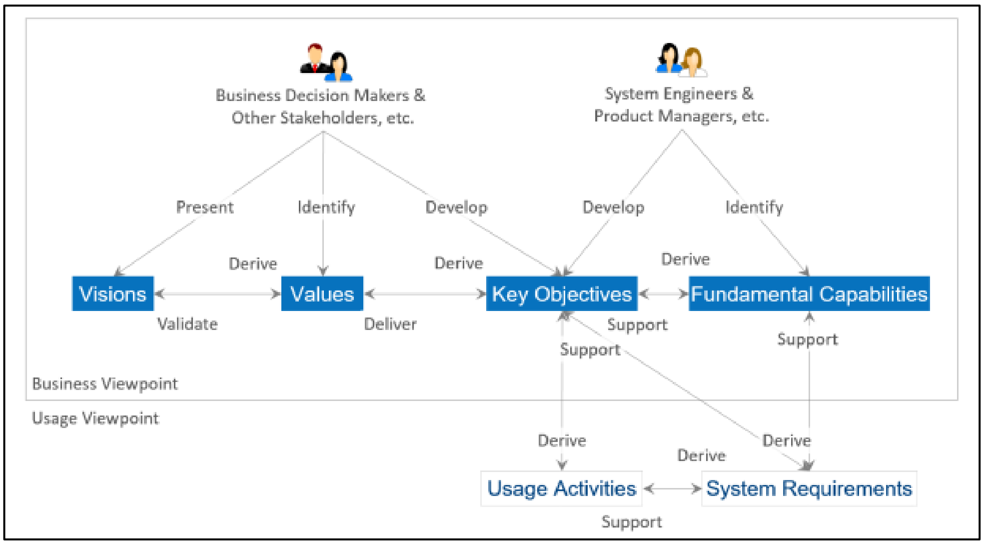


Figure 35. A Vision and Value-Driven Model.

For the business viewpoint definition, the main elements will be considered:

- **Vision**, this section describes the stakeholder's business direction with respect to the organisation and reflects how the stakeholder may perceive that vision.
- **Values**, this section describes how stakeholders perceive the vision of the company and how they participate in the implementation of AIDEAS solutions.
- **Key objectives** are the quantifiable technical means that allow the business level to know what is expected from AIDEAS solutions in the context of values. Objectives should be time-bound and measurable.
- **Fundamental capabilities**, this item will provide a high-level view of the capabilities of AIDEAS solutions to complete key business objectives.

5.2.1 Stakeholder's classification

In order to situate the stakeholders who, have a direct interest in the company, or primary stakeholders, it is necessary to consider each phase of the machine's life cycle. In each phase of the life cycle, different types of profiles are found, from designers to maintenance personnel. The following table shows a classification of primary stakeholders (Table 1. This classification considers both the phase in which they are involved (Design/Manufacturing/Use/Repair-Reuse-Recycle Phase) and the level they are at (High/Medium/Low Level). To understand the table, the type of stakeholder according to the life cycle stage is explained first:

- **Design Phase**: Stakeholders in charge of the tasks of machine design, creation of new designs, modification of an existing design, development of design parameters, collaboration with other teams, etc. This type of profile must have technical knowledge related to the design and operation of the machine.
- **Manufacturing Phase**: Stakeholders in charge of the tasks of supplying, manufacturing, and delivering the machine. Within this phase, there are both strategic and operational profiles, as this phase requires a long- and short-term vision.
- **Use Phase**: Stakeholders in charge of monitoring the state of the machine once it has been delivered to the customer. The correct operation of the machine is the objective of this phase, so the profile of this phase will be expert profiles in the machine and in its correct use to guarantee optimum quality.
- **Repair-Reuse-Recycle**: Stakeholders in charge of returning the machine to the previous phases to improve the sustainability of its removal, offering a second life to the machine or use of its components. This type of profile must have technical knowledge of the environment, and analytical and mechanical skills to identify the different alternatives that the machine can take.

Secondly, the level of the position is explained according to the responsibility of each position.

- **High-Level**: This level of management is responsible for setting the organization's direction, making strategic decisions, and ensuring alignment between the company's goals and values. Top-level executives communicate with the board of directors and shareholders to ensure the company's success.
- **Medium-Level**: Department heads, managers, and supervisors comprise middle-level management. They translate the strategic goals set by top-level management into actionable tasks for their teams. They are responsible for ensuring their departments meet objectives within budget and on time while communicating the company's vision to lower-level employees.
- **Low-Level**: Team leaders and supervisors comprise the first-line management or supervisory level. They oversee daily employee activities, providing guidance, support, and managing

workloads to ensure employees meet their targets. They ensure efficient and effective performance, making them crucial to the organization's success.

<table>
<tr><th colspan="6">Design Phase (Enterprise site)</th></tr>
<tr><th colspan="3">High-Level</th><th colspan="3">Medium-Level</th></tr>
<tr><td colspan="3">Product/Machine Manager</td><td colspan="3">Machine Design Engineer</td></tr>
<tr><td colspan="3"></td><td colspan="3">CAD (Computer-Aided Design) Engineer</td></tr>
<tr><th colspan="6">Manufacturing Phase (Enterprise site)</th></tr>
<tr><th colspan="2">High-Level</th><th colspan="2">Medium-Level</th><th colspan="2">Low-Level</th></tr>
<tr><td colspan="2">Purchasing Manager</td><td colspan="2">Material Planner</td><td colspan="2">Assembler</td></tr>
<tr><td colspan="2">Planning Manager</td><td colspan="2">Process support engineer</td><td colspan="2">Processing operators</td></tr>
<tr><td colspan="2">Processing Manager</td><td colspan="2">Production Schedulers</td><td colspan="2"></td></tr>
<tr><td colspan="2">Director of Operations</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Supply Chain Manager</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><th colspan="6">Use Phase (Customer site)</th></tr>
<tr><th colspan="3">High-Level</th><th colspan="3">Medium-Level</th></tr>
<tr><td colspan="3">Quality Control Manager</td><td colspan="3">Quality Assurance (QA) Engineer</td></tr>
<tr><td colspan="3">After Sales Service Manager</td><td colspan="3">Quality Analyst</td></tr>
<tr><td colspan="3"></td><td colspan="3">Technical Service</td></tr>
<tr><td colspan="3"></td><td colspan="3">Process Engineer</td></tr>
<tr><td colspan="3"></td><td colspan="3">Data Analyst</td></tr>
<tr><th colspan="6">Repair-Reuse-Recycle Phase (Customer site)</th></tr>
<tr><th colspan="3">High-Level</th><th colspan="3">Medium-Level</th></tr>
<tr><td colspan="3">After Sales Manager</td><td colspan="3">Sustainability Engineer</td></tr>
<tr><td colspan="3">Retrofit Project Engineer</td><td colspan="3">Customer support</td></tr>
</table>

Table 1. Classification of primary stakeholders.

Considering all the stakeholders defined above, you can find all the in-depth information in **next tables:**

Stakeholder Name	Description (business viewpoint)	Type
Solution developers	Developers of the AIDEAS solutions involved in the daily outputs of the project	Operational
Partner level coordinators, Pilots and Experts	Coordinators at the partner level, AIDEAS Pilots, Business legal and standardization experts who advise and make decisions on the short-term implementation and development of the solutions.	Tactical
Project and Technical Coordinators	They have the overall vision of the project and take strategic and long-term decisions to give direction to the AIDEAS developments	Strategic

Table 2. Description of the stakeholder type

Stakeholder Name	The name of the stakeholder
Vision	Describing a future state of an organization or an industry, including the business direction toward which an organization executes and providing values reflecting how the vision may be perceived
Values and experiences	Reflecting how the vision may be perceived by the stakeholders involved in funding the implementation of AIDEAS Solutions as well as by the users of the resulting project tools.
Key objectives - business	List of quantifiable high-level business outcomes expected of AIDEAS Solutions in the context of delivering the values. ***Key objectives*** are **quantifiable** high-level **technical and** ultimately **business outcomes expected of the resultant system in the context of delivering the values**. Key objectives should be measurable and time-bound. Senior business and technical leaders develop the key objectives.

Table 3. Scope of the definition of stakeholders

Stakeholder Name	The name of the stakeholder
Scenario and Processes Involvement	List of the processes involved in the achievement of the business objectives
Key objectives – business	List of the business outcomes, already defined by the business and decision-makers, from which the technical objectives are derived
Key objective – technical	List of quantifiable high-level technical **outcomes expected of** AIDEAS **Solutions** in the context of delivering the values
Fundamental capabilities	High-level specifications of the essential ability of AIDEAS Solutions to complete the technical objectives 1 tasks. I want to: • Functional capability 1 • Functional capability N

Table 4. Template for Business & Decision makers.

Stakeholder Name	Equipment manufacturers – Decision makers/Managers
Vision	Being seen as an innovative and environmentally responsible manufacturer of high-quality equipment.
Values and experiences	They will benefit from the results of the AIDEAS project by having a comprehensive system, based on AI technologies, for the improvement of processes throughout the entire life cycle of industrial equipment (design, manufacture, use and repair/reuse/recycling).
Key objectives - business	• Reduce machine design time by X% • Improve predictive maintenance to reduce machine downtime • Optimize production processes to minimize waste by X% • Optimize production processes to reduce defects by X% • Reduce production time by x% • Recovery of X% of machines for a second life in other markets

Table 5. Template for Internal Technical Personnel

Stakeholder Name	Processing operators
Use-case	Control production and maintain high-quality standards
Values and experiences	Minimize downtime Minimize waste Keep production costs under control
Key objectives - technical	• Reduce rejection rate by X% • Reduce machine downtime • Minimize waste by X%

Table 6. Processing operators

Stakeholder Name	Production scheduler
Use-case	Control production times and machine uptime
Values and experiences	Minimize downtime Minimize production times Improve scheduling and planning
Key objectives - technical	• Reduce machine downtime • Receive real-time process information • Reduce scheduling decision time

Table 7. Production scheduler

Stakeholder Name	Assembler
Use-case	Responsible for assembling parts or components to create a final product
Values and experiences	Improving assembly efficiency Enhancing quality control Troubleshooting and resolving issues Improving collaboration and communication
Key objectives - technical	• Reduce assembly time by x% • Reduce assembly costs by x% • Increase in production output • Reduce defective products by x% • Reduce communication errors

Table 8. Assembler

Stakeholder Name	Process support engineer
Use-case	Control production lines and processes
Values and experiences	Minimize downtime Minimize production times Consistently meet deadlines

Key objectives - technical	• Receive real-time process information • Improve early warning detection of problems • Minimize waste • Reduce costs

Table 9. Process support engineer

Stakeholder Name	Product engineer
Use-case	R&D, product design and engineering
Values and experiences	Improve quality Reduce production costs Reduce production times
Key objectives - technical	• Identify what factors affect product quality and functionality Improve product quality and function Visualize the impact of design changes on production costs and times Controls costs of new or improved products

Table 10. Product engineer

Stakeholder Name	Quality manager
Use-case	Assure production quality
Values and experiences	Improve quality Improve customer satisfaction Reduce production times Certify quality in a simple way
Key objectives - technical	Reduce the need for additional work by X% Improve customer satisfaction by % Quickly identify issues and underlying factors

Table 11. Quality manager

Stakeholder Name	Maintenance team
Use-case	Schedule and deliver maintenance operations in an optimal way
Values and experiences	Reduce machine downtime Reduce disruptions in production Early warning systems for clients with maintenance needs Early warning detection of failures or production defects
Key objectives - technical	Reduce maintenance costs by % Reduce machine downtime by %

Table 12. Maintenance team

Stakeholder Name	Product/Machine Manager
Use-case	Responsible for managing the product life cycle of a specific machine model, from design to end-of-life
Values and experiences	Customer focus Strategic thinking Data-driven decision-making Accountability
Key objectives - technical	• Project Management • Data Analysis • Quality Control • Risk Management

Table 13. Product/Machine Manager

Stakeholder Name	Computer-Aided Design Engineer
Use-case	The Computer-Aided Design (CAD) engineer is responsible for creating the initial 3D model of the car using specialized software
Values and experiences	Proficiency in CAD software Knowledge of engineering principles Technical drafting skills Project management experience Attention to detail Creativity
Key objectives - technical	• Designing 2D and 3D models • Developing technical drawings • Conducting design analysis • Maintaining CAD systems • Conducting design analysis

Table 14. Computer-Aided Design Engineer

Stakeholder Name	Material Planner
Use-case	Responsible for ensuring that there is an adequate supply of raw materials to meet production demands
Values and experiences	Knowledge of supply chain management Experience with ERP systems Familiarity with industry-specific regulations Organizational skills Attention to detail Organizational skills
Key objectives - technical	• Demand Forecasting • Inventory Management • Supplier Management • Production Planning • Analytical Skills • Strategic Thinking

Table 15. Material Planner

Stakeholder Name	Processing Manager
Use-case	Responsible for bringing a product from its initial conception to the production line, ensuring that all technical specifications are met and that the product generates a sufficient profit for the company.
Values and experiences	Ensure product's conformity to customers' technical specifications Monitor the procedure of cost analysis at each stage of development. Enhance existing products via process enhancements Supervised and troubleshooting the product throughout its production.
Key objectives - technical	• Reduce the costs of the production process by X% • Minimize production inefficiencies and waste by X% • Automate the evaluation of the product quality conformity

Table 16. Processing Manager

Stakeholder Name	Purchasing Manager
Vision	Being perceived as an environmentally conscious company, with a clear understanding of the equipment lifecycle and the impact of the circular economy.
Values and experiences	They will benefit from a transparent understanding, as well as an optimization, of the Capital and Operational Expenditures
Key objectives - business	• Reduce CapEx and OpEx. • Improved financial predictability (knowing when future purchases will be needed and controlling the cash flow). • Improved inventory management.

Table 17. Purchasing Manager

Stakeholder Name	Data analyst
Use-case	Responsible for gathering and analysing data to garner insights, in an attempt to make better business decisions.
Values and experiences	Gather data from customer feedback. Clean and process the data to achieve a proper data format. Analyse and interpret data to extract information. Store and retrieve the acquired knowledge. Present the analysis results using visualizations.
Key objectives - technical	• Facilitate the acquisition and storage of the data through the provided data management platform • Assist in the data analysis process with the provision of AI algorithms to improve the detection of product defects by X%. • Present insightful information through graphs and charts using the provided dashboards.

Table 18. Data analyst

Stakeholder Name	Retrofit Project Engineer
Vision	Promoting sustainability in the manufacturing industry by reducing waste, conserving resources and extending the life cycle of machines. Creating a circular economy in order to minimize the environmental impact of manufacturing.

Values and experiences	Minimize repairing time Identify past repairs and issues Understand the machine's performance Assess the machine's condition Ensure regulatory compliance
Key objectives - business	• Reduce repair time by x% • Reduce repair costs by x% • Increase the machine's efficiency and output • Reduce waste and environmental impact • Improve regulatory compliance

Table 19. Retrofit Project Engineer

Stakeholder Name	After Sales Manager
Vision	A caring after-sales service that ensures continuous smooth operations of the delivered products, empowered by a circular economy cycle.
Values and experiences	It will establish a caring and diligent after-sales process, that will ensure the optimal operation on the client's side, with an emphasis on circularity and long-term product lifecycles.
Key objectives - business	• Increase machine remanufacturing and repurposing. • Improve machine end-of-life customer support. • Increased number of referrals to new customers by x%

Table 20. After Sales Manager

Stakeholder Name	Customer Support
Use-case	Responsible for providing assistance to clients who are having issues with a company's products or services.
Values and experiences	Documenting consumer interactions, transactions, feedback, and complaints. Offering feedback regarding the effectiveness of the customer service procedure. Recognizing and addressing customer complaints.
Key objectives - technical	• Facilitate the acquisition and storage of the data coming from customer interactions through the provided data management platform. • Assist in the presentation of customer feedback effectiveness through insightful graphs and charts. • Exploit the data deriving from customer feedback using AI algorithms, to assist in the production reconfiguration to minimize complaints by X%

Table 21. Customer Support

Stakeholder Name	Supply Chain Manager
Vision	Environmentally conscious company with efficient resource management achieved through a holistic understanding of all processes and stakeholders in the supply chain
Values and experiences	They will benefit from efficient, cost-effective, and sustainable operations, from procurement to delivery to customers.
Key objectives - business	• Predictable coordination with suppliers (earlier procurement start, reduction of delays of material supply, reduction of payment time) • Improved inventory management. • Improved performance of the supply chain.

Table 22. Supply Chain Manager

Stakeholder Name	After Sales Service Manager
Vision	A caring after-sales service that ensures continuous smooth operations of the delivered products.
Values and experiences	It will establish a caring and diligent after-sales process, that will ensure the optimal operation at the client's side.
Key objectives - business	• Reduction of x% of maintenance actions. • Reduction of x% of downtime of equipment. • Reduction of x% on the OpEx in after-sales services (automated reports, operations, etc.) • Reduced the number of customer complaints. • Improved customer satisfaction. • Increased number of referrals to new customers by x%

Table 23. After Sales Service Manager

5.2.2 Roles

In the ever-evolving digital landscape, effective data management and utilization have become crucial for organizations in various industries. To facilitate seamless data sharing and utilization, a well-defined ecosystem has been established, comprising several key roles. These include the data owner, data provider, data consumer, data user and service provider. Each plays a critical role in ensuring the categorization, protection, integrity and controlled access to valuable data sets. Here we can see those defined within the AIDEAS project.

- **Data Owner:** The Data Owner is a senior-level individual who is accountable for the categorization, protection and integrity of one or more data sets. The Data Owner has the responsibility to define data usage policies and contracts, while also determining the payment model for the provision of this data to third-party users.
- **Data Provider:** The Data Provider is granted permission by the Data Owner to make the data accessible to Data Consumers. The procedure of data exchange and the publication of metadata must adhere to the International Data Spaces reference architecture model.
- **Data Consumer:** The Data Consumer is ingesting data by the Data Provider In the majority of instances, the Data Customer requests specific datasets directly from the Data Provider, but in the case of retrieving data from multiple data suppliers, an inquiry must be made at a Data

Intermediary which provides the necessary metadata for a Data Consumer to connect to a Data Provider.

- **Data User:** The Data User is the legal entity with the right to use and exploit the data provided by the Data Owner, in accordance with the defined data usage policy. Depending on the, sometimes the Data User and the Data Consumer can be in identical roles.
- **Service Provider:** The Service Provider is a participant in the International Data Spaces (IDS) framework that offers services like data analysis, integration, cleansing, or enrichment. They receive data, perform operations, and deliver results to the same entity or a designated recipient. They can install apps in their IDS connector and act as a Service Broker, providing metadata on available services to assist other participants.

Following the explanation of each type of existing role, it is necessary to identify within each project suit what type of role each stakeholder defined in the previous section plays. **Error! Reference source not found.** represents the design suit, **Error! Reference source not found.** represents the production suit, **Error! Reference source not found.** represents the use suit, and **Error! Reference source not found.** represents the recycling suit.

	Product/ Machine Manager	Machine Design Engineer	CAD Engineer	Purchasing Manager	Material Planner	Assembler
Data Owner	X	(X)	(X)	(X)	(X)	X
Data Provider	X	(X)	X	X	X	(X)
Data Consumer	-	X	X	(X)	X	-
Data User	(X)	X	X	(X)	X	(X)
Service Provider	-	X	X	-	X	X

Table 24. Mapping data roles with stakeholders from the design phase.

	Planning Manager	Process support engineer	Processing operators	Processing Manager	Production Schedulers	Director of Operations
Data Owner	(X)	-	-	(X)	(X)	-
Data Provider	X	X	-	(X)	X	X
Data Consumer	-	X	(X)	X	(X)	(X)
Data User	(X)	(X)	X	X	-	X
Service Provider	(X)	-	X	(X)	(X)	X

Table 25. Mapping data roles with stakeholders from the manufacturing phase.

	Supply Chain Manager	Quality Control Manager	Quality Assurance Engineer	After Sales Service Manager	Quality Analyst	Technical Service
Data Owner	X	(X)	-	(X)	(X)	-
Data Provider	X	X	X	X	X	(X)
Data Consumer	(X)	(X)	(X)	(X)	X	(X)
Data User	(X)	X	X	(X)	X	X
Service Provider	-	X	-	-	-	X

Table 26. Mapping data roles with stakeholders from the use phase

	Process Engineer	Data Analyst	After Sales Manager	Sustainability Engineer	Retrofit Project Engineer	Customer support
Data Owner	(X)	(X)	(X)	(X)	(X)	-
Data Provider	X	X	X	X	X	(X)
Data Consumer	X	X	(X)	X	X	X
Data User	X	X	-	X	X	-
Service Provider	-	(X)	X	-	-	X

Table 27. Mapping data roles with stakeholders from the repair-reuse-recycle **phase.**

5.3 AIDEAS Usage, Functional and Implementation Viewpoint

The usage viewpoint task will oversee defining how to implement the capabilities and structure of the AIDEAS Framework. To do so, this task will start by identifying the four key elements of the Usage viewpoint: the tasks, roles, activities and parties in AIDEAS, taking into account both human beings and hardware/software systems. Once these elements have been identified, the process will go one level deeper and will define the functional map, the implementation maps and specify the role responsible for the execution of the task. Once tasks are fully characterised, we will define other elements of an activity, i.e., triggers that start the activity, workflows that define the organisation of the tasks within the activity, effects that will produce the execution of the activity on the system and the constraints of its execution.

The functional viewpoint task will decompose the AIDEAS Framework into functional components, grouped into different functional domains: Control (functions performed by industrial control and automation systems), Operations (management and operation of the control domain), Information (managing and processing data), Application (functions implementing application logic that realises specific business functionalities) and Business (functions supporting business processes and procedural activities). Then, the functional viewpoint will describe the data, decision and command/request flows circulating among the different functional components, thus identifying the main interfaces between them as well as with external elements in the environment. Once this decomposition has been performed, it will elaborate on the controls, coordination and orchestration mechanisms exercised from each of these domains using sequence diagrams to describe the most relevant usages and activities of the overall system.

Finally, the implementation viewpoint will describe, technically, the different components of the AIDEAS Framework, how they are interconnected and perform a selection of technologies that are required for its proper implementation. Among other things, this task will use as inputs the results of the business viewpoint and the set of activities identified in the usage viewpoint, which will provide implementation maps for the associated implementation components.

5.4 Information Domain

The information layer plays a fundamental role in establishing an information model, a common domain-independent language, which acts as a vocabulary for data spaces. Its main objective is to enable the (semi-)automated exchange of digital resources within a trusted ecosystem made up of distributed parts while preserving the data sovereignty of the Data Owners. The Information Model has the function of describing, publishing and identifying data products and reusable data processing software, which are known as Digital Resources. This formal model facilitates the identification of relevant resources, which in turn enables their exchange and consumption through easily discoverable services.

5.4.1 Machine Passport (MP)

The MP is designed to store and share manufacturing data collected throughout the various phases of the product life cycle, including the Design, Manufacturing, Use, and Repair-Reuse-Recycle. It aims to develop data exchange protocols, standards, and interfaces that facilitate smart, trustworthy data integration, sharing, and exchange across different types of computer-aided systems and manufacturing stages (Figure 36).

To accomplish this, a smart platform will be used to acquire, manage, and share large-scale manufacturing data from multiple sources, which can be viewed through various devices and dashboard interfaces.

The Machine Passport includes functionalities for acquiring and storing multi-source manufacturing data gathered during the different product life phases. It also provides methods for retrieving requested knowledge and facilitates components for pre-processing the acquired data, ensuring compatibility, interoperability, consistency, and acceptable quality of manufacturing data.

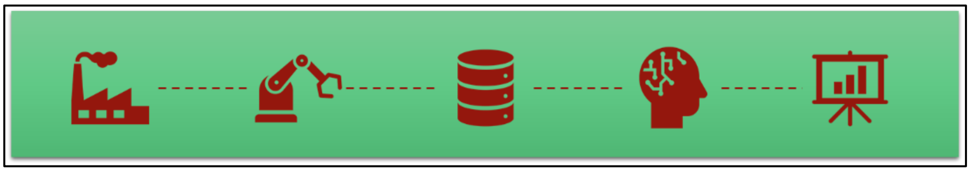


Figure 36. Workflow of data.

MP utilizes Explainable AI algorithms to guide the orchestration of large-scale data flow and knowledge management throughout the manufacturing phase of the product life cycle. Through the manipulation of machine learning knowledge, MP facilitates decision-making processes related to the product life cycle, guiding optimal configuration strategies for repairing, reusing, and recycling industrial equipment (Figure 37).

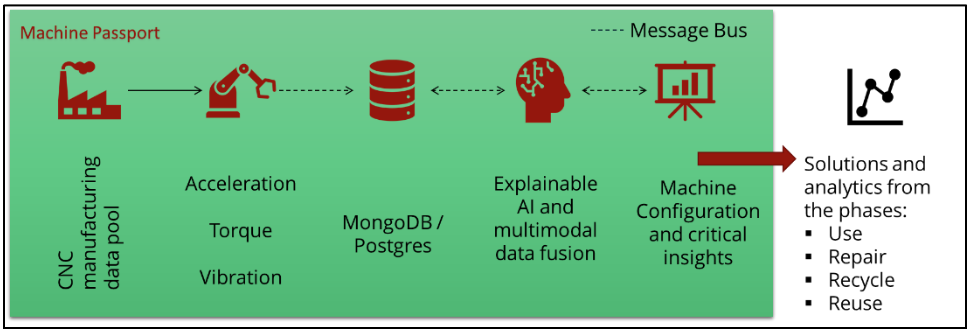


Figure 37. Analytical workflow of data.

MP will receive both static data from sources such as Excel and CSV files, and dynamic processed data from sensors. Preprocessing requirements and implementation will be defined by the specific solutions depending on the situation. After receiving the data, Machine Passport will store it in connected databases. Additionally, Machine Passport will gather, and store knowledge produced by different solutions and XAI models (Figure 38). Finally, available knowledge can be retrieved by the different solutions and UIs by requesting it from the Machine Passport.

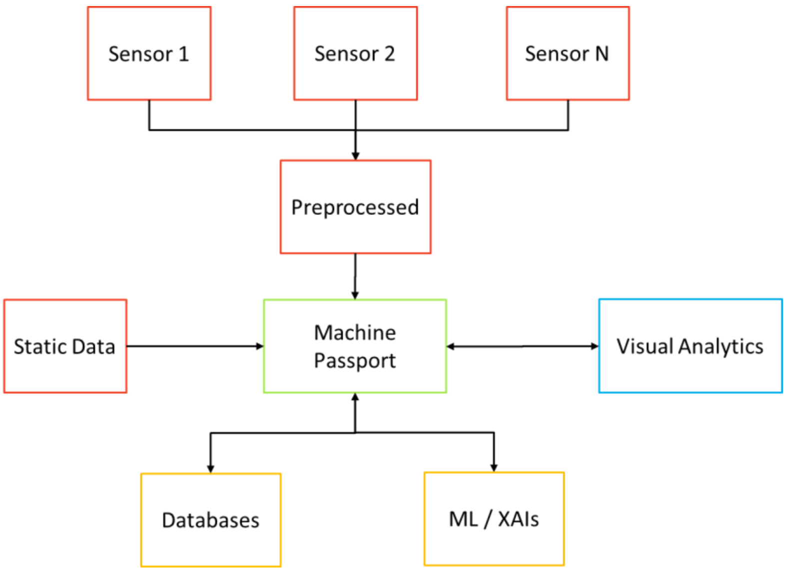


Figure 38. General pipeline of Machine Passport.

The MP will incorporate robust security functionalities to safeguard the data. Authentication will be performed on every HTTP request to validate the component's authenticity. This will involve verifying the credentials stored in the Postgres database. Upon successful verification, an authorization token with a specified expiration time will be generated. This token will grant access to the MP's controller endpoints, and it will contain information about the role and authorized endpoints. Whenever the component needs to perform an action, the validity of the authorization token will be verified.

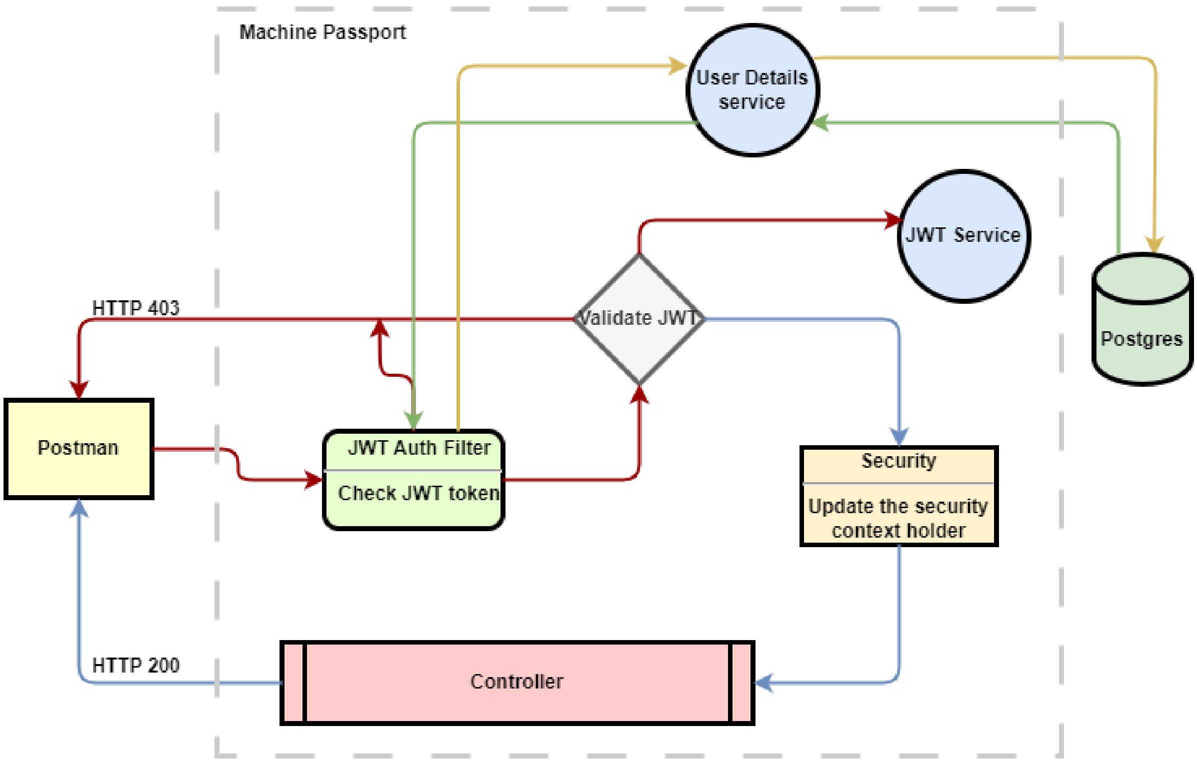


Figure 39. Security of Machine Passport.

Usage Viewpoint
Description
The MP will be a web app, which will be able to connect to different machines and visualize information concerning the life-cycle of the machine.
Use Model

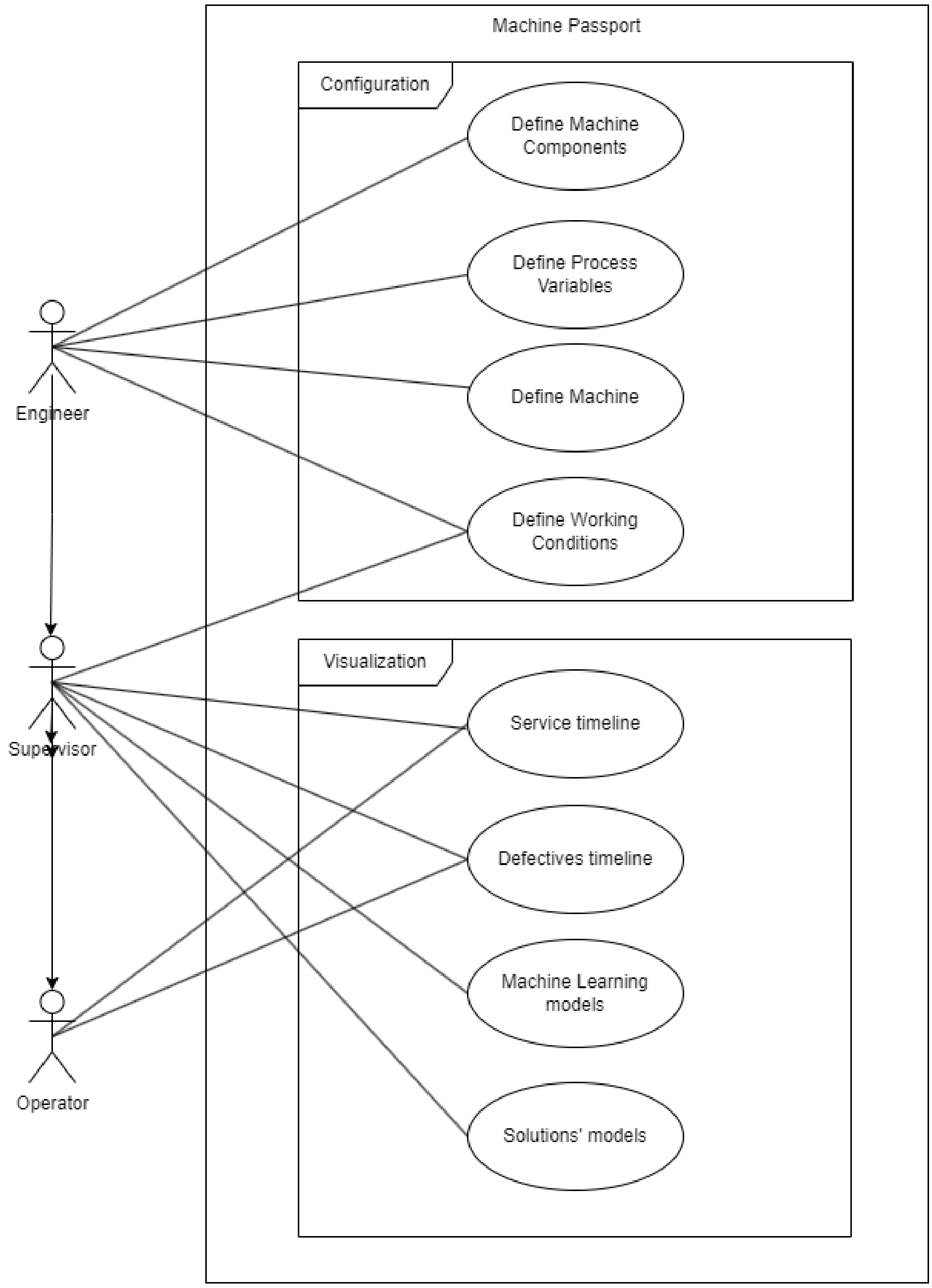


Figure 40. MP Use Model.

Functional viewpoint	
Description	
Description	Machine Passport is responsible for storing and sharing manufacturing data that are obtained throughout the product life phases, i.e., Design, Manufacturing, Use, and Repair-Reuse-Recycle Data phases of Industrial Equipment.
Inputs	As inputs, we will have static and dynamic data. Static data will come from data files (csv, excel). The dynamic data will come from sensors and from the solutions.
Outputs	MP will contain functionalities to provide requested knowledge when it is requested.

Functional diagram

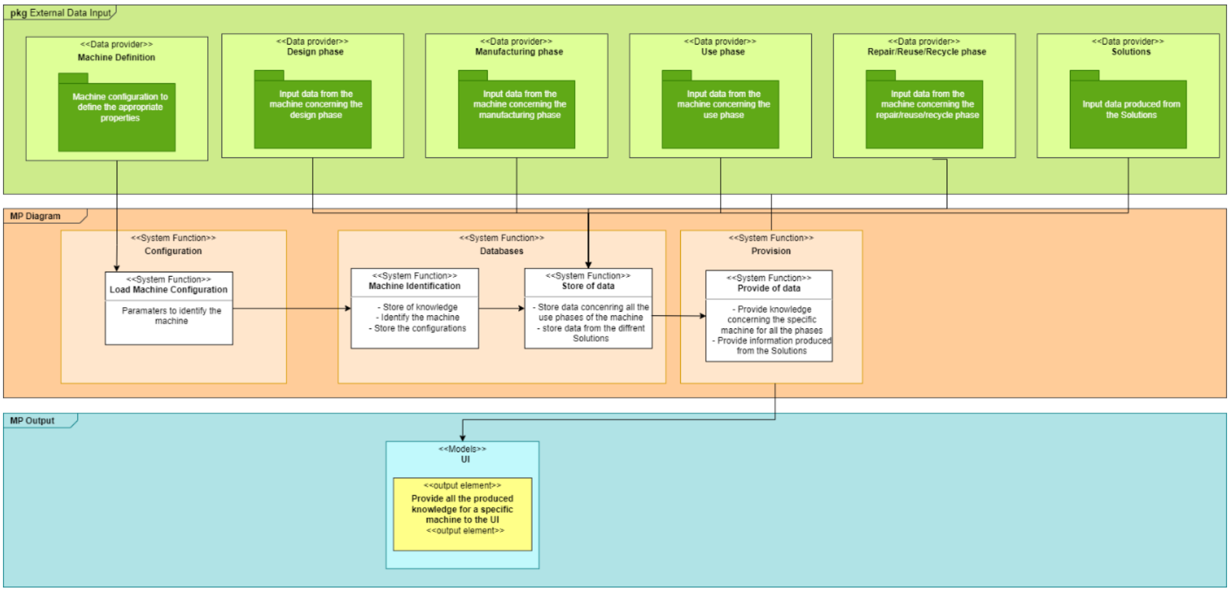


Figure 41. MP functional diagram.

Implementation Viewpoint

Description of implementation Component

Responsible for data acquisition and sharing through all the phases of the product's life.

Technical Description of its Components

Dependencies	Development Language: - JAVA Libraries: Spring Boot, PostgreSQL, Lombok, JJWT Container: Docker Database need: MongoDB, PostgreSQL
Interfaces	User Interface: No Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MongoDB, PostgreSQL
Requirements	JAVA 17, JAVA IDE (Eclipse, InteliJ), PostgreSQL 15, MongoDB.
Installation process	Import the component as a Maven project in the JAVA IDE, run PostgreSQL and MongoDB locally and run the main.java file in the IDE.

Solution architecture

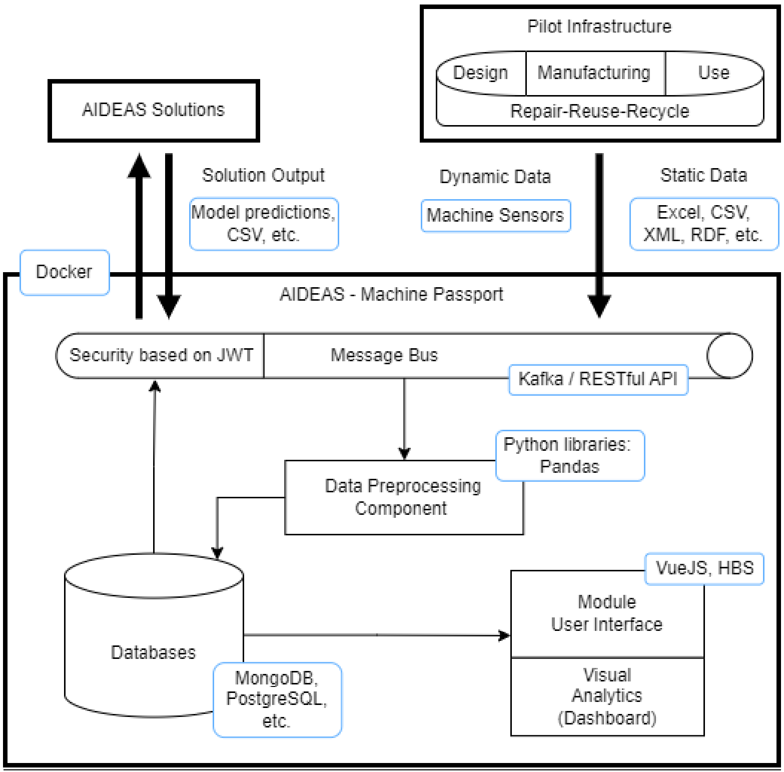


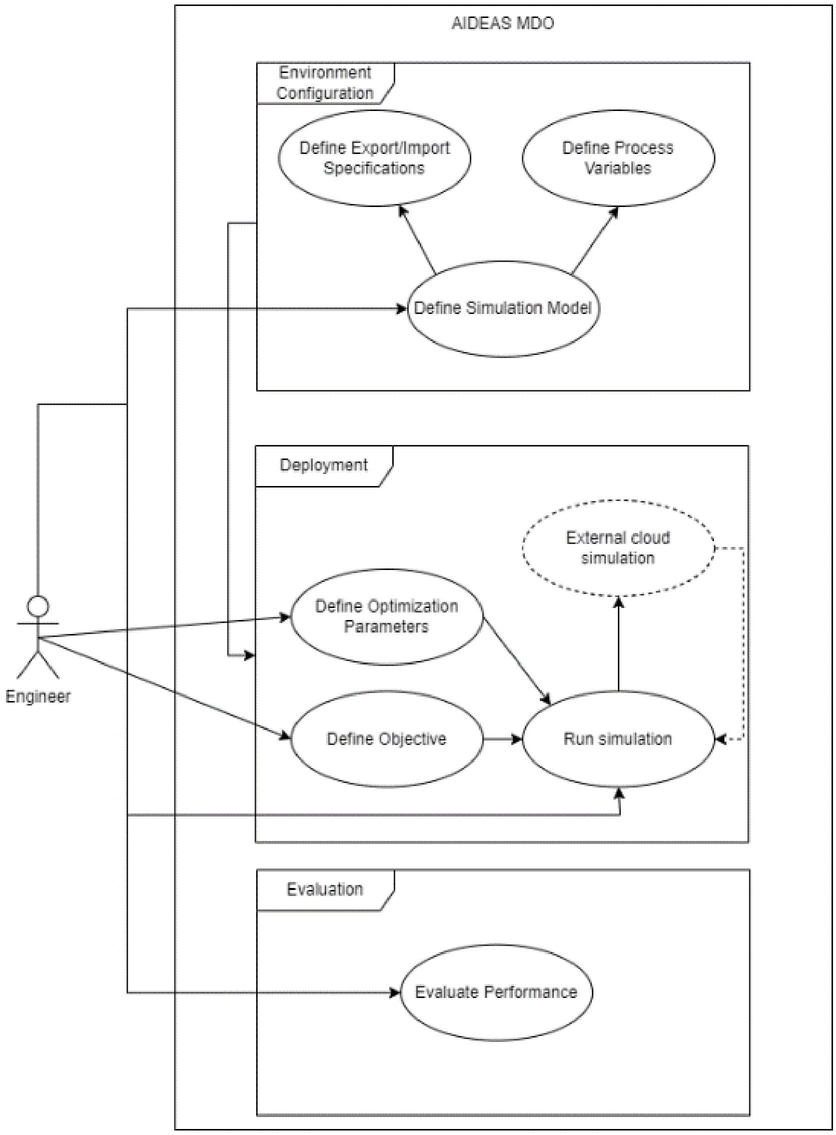
Figure 42. MP implementation architecture.

Details about architecture
MP solution is developed in Java using Spring Boot, PostgreSQL, Lombok, and JJWT. It leverages Docker for containerization, and the data repositories consist of MongoDB and Postgres. The solution communicates through RESTful APIs over HTTP/HTTPS protocols. The setup process involves importing the Maven project, running local instances of Postgres and MongoDB, and executing the main.java file in a Java IDE. The solution does not have a user interface. Instead, it exposes RESTful APIs for synchronous and asynchronous communication. The APIs utilize the HTTP/HTTPS protocols. To set up the solution, the component needs to be imported as a Maven project in a Java IDE. Postgres and MongoDB should be run locally. Finally, the main.java file in the IDE can be executed to run the solution.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/MP.html

5.5 Application Domain

This application domain is responsible for providing specific application services to the system. It encompasses solutions related to the implementation of specific industrial applications, such as process control, condition monitoring and predictive maintenance. It, therefore, plays a key role in the implementation of specific services in the system. In the following, we will describe the different applications of AIDEAS from the three points of view (Usage, Functional and Implementation).

5.5.1 MDO (Machine Design Optimiser)

Usage Viewpoint
Description
Environment configuration: MDO user (operator) defines the process parameters for the MDO Module. These parameters are mainly of the machine to analyse, the simulation model (for model-based approach) or the experimental database (for data-based approach). Based on this information the user must define the objective and the design parameters to use for the optimization process. **Deployment:** Based on the information defined in the previous step the operator configures the parameters of the optimization process (tolerances, maximum time, etc). As output the user will receive the optimal parameter proposal, and some sensibility graphs to evaluate the robustness of the solution.
Use Model
 **Figure 43.** MDO Use Model.

Functional viewpoint	
Description	
What	The main feature of this component is to find the optimal configuration of design parameters that gives the best performance of the machine.
Who	Design Engineer
Where	Enterprise Tier
Why	To find the best performance design for the application

Functional diagram

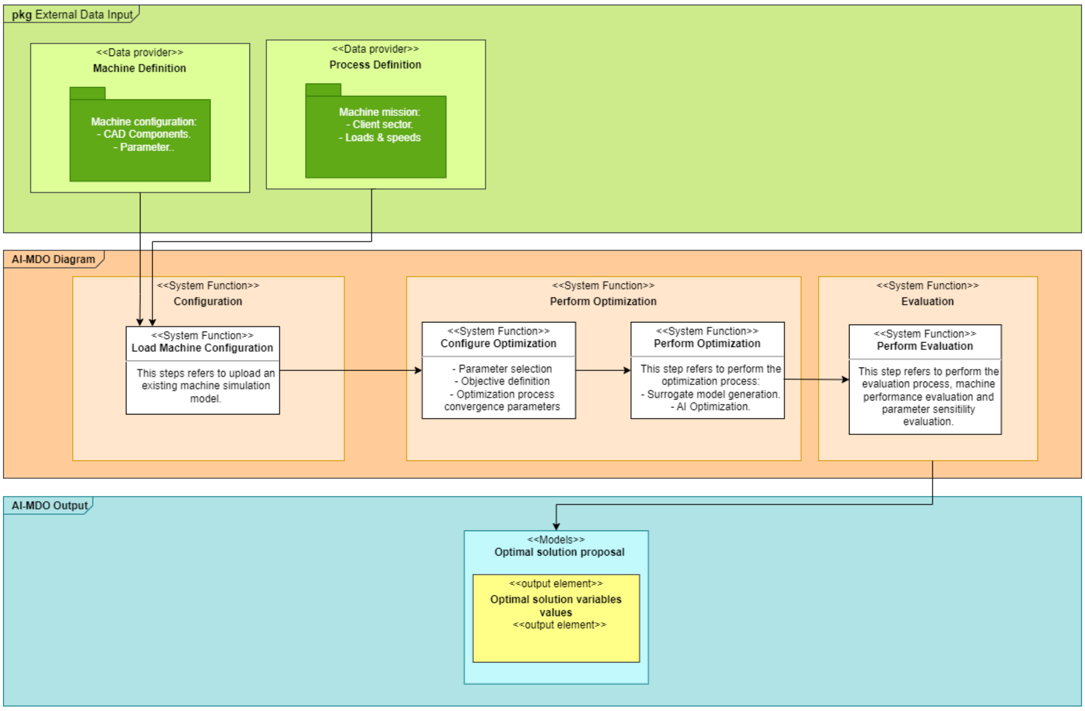


Figure 44. MDO functional diagram.

Implementation Viewpoint	
Description of implementation Component	
AI-MDO is a toolkit to optimally define the key design parameters of a machine considering its whole life.	
Technical Description of its Components	
Dependencies	Development Language: - Python Libraries: NumPy, Pandas, SciPy, Keras, Py Torch, TensorFlow Container: Docker Database need: MongoDB
Interfaces	User Interface: Yes, REACT Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MongoDB

Requires	Other AIDEAS Solutions: N/A

Solution architecture

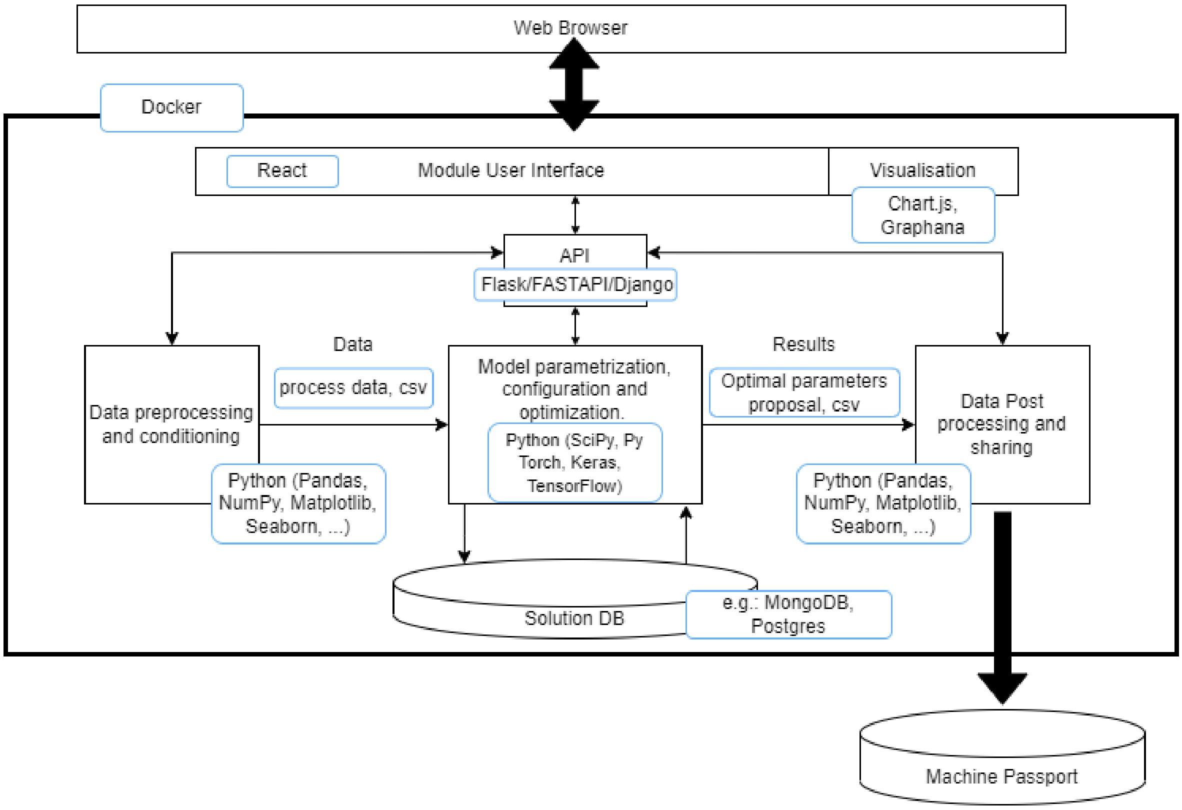


Figure 45. MDO implementation architecture.

Details about architecture

AI-MDO's backend will be developed in Python using the most common libraries used in data science and machine learning, such as NumPy for array and matrix processing, Pandas for data analysis and processing and SciPy, Keras, Py Torch and TensorFlow for training and evaluating machine learning models. **AI-MDO**'s frontend will be developed in REACT, which is a JavaScript library, Redux will be used to manage the application state. Both backend and frontend, will be communicated over a RESTful API using HTTPS protocols. The API could be tested using tools such as Postman. Docker, which is a platform to build, deploy, run and manage containers, will be used to package everything the software needs to run.

More information here: https://viewpoints.aideas-srv.cigip.upv.es/MDO.html

5.5.2 MDG (Machine Synthetic Data Generator)

Usage Viewpoint
Description
The user interaction with our system is organized into four separate, yet interdependent layers. Each layer interacts with stored project data, and although there is a natural workflow, each layer can be accessed independently. Initially, users work with the geometry subsystem to create the machine', utilizing data from rheological or other external measurements to define fluid and solid material properties. This process involves the automatic construction of Computer Aided Engineering (CAE) solids, which provide early visuals that are combined to form the digital twin. After the digital twin has been assembled, users then finalize a 3D model. Once this model is completed, it can be visualized, saved, modified, and even exported for real-world construction. Typically, at least one full simulation cycle is performed at this stage. Next, the prediction subsystem provides AI inference capabilities on the 3D model. This includes pre-trained performance models that enable real-time performance estimations of the prototype, offering valuable insights to the user. Simultaneously, users have the flexibility to define material properties used in viscosity terms by the numerical solver. These properties are eventually combined with the digital twin and other process data in the simulation subsystem. Finally, the system allows for the creation of simulation batches which can be enqueued and processed by the compute grid. This detailed and layered process ensures a comprehensive interaction between the user and the system, ultimately leading to a precise and predictive digital twin.
Use Model

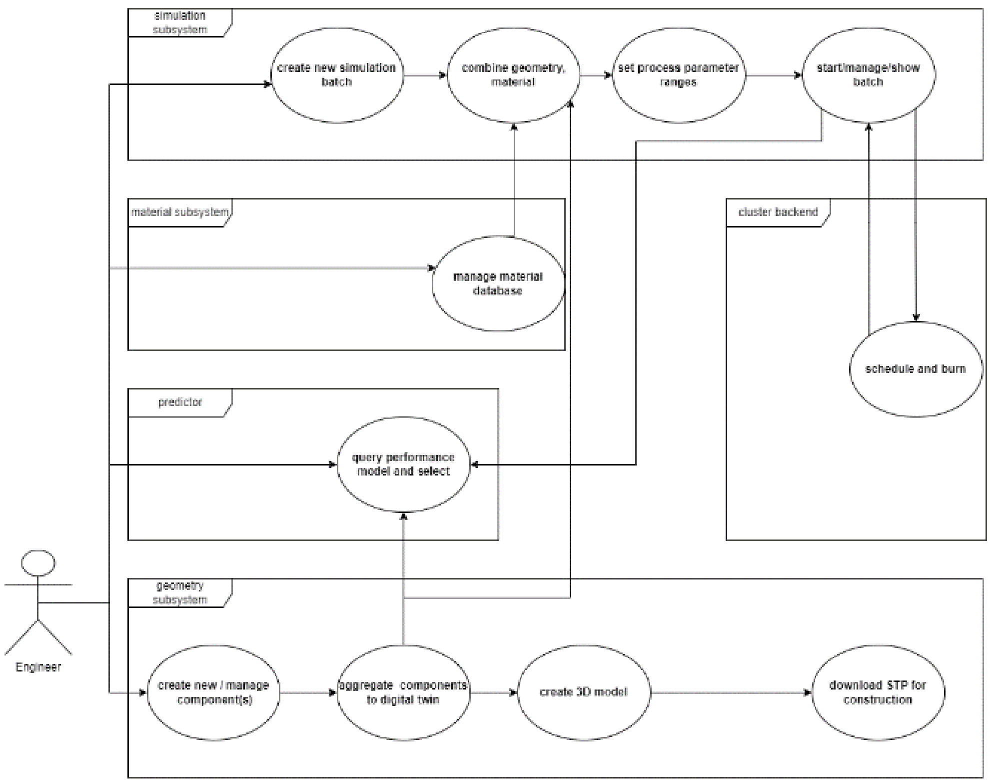


Figure 46. MDG Use Model.

Functional viewpoint

Description	
What	Data generator for synthetic data with physics simulation kernel.
Who	Engineers in a rapid prototyping workflow.
Where	Enterprise layer.
Why	Generate bulk data and derivatives from simulation for training AI prediction- and generative models where sensor (real-world) data is missing.

Functional diagram

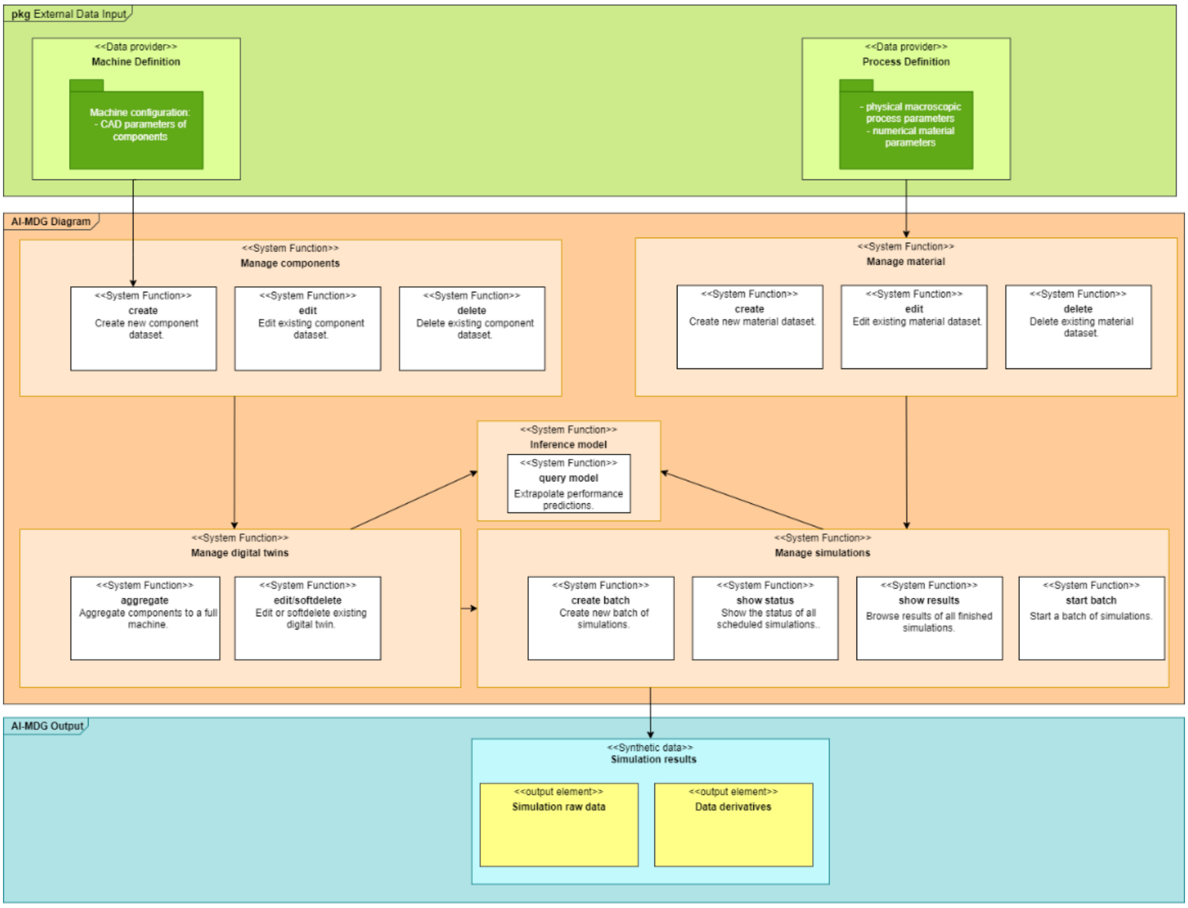


Figure 47. MDG functional diagram.

Implementation Viewpoint

Description of implementation Component

MDG provides support for the integrations of AIDEAS AI-based solutions to generate a Machine synthetic data.

Technical Description of its Components

Dependencies	Development Language: - Python Libraries: Py Torch, OpenCV, Scikit Container: Docker Database need: MongoDB, Postgres
Interfaces	User Interface: Yes, REACT Synchronous/Asynchronous Interface: RESTful APIs

	Network/Protocols: HTTP/HTTPS Data Repository: MongoDB
Requires	Other AIDEAS Solutions: N/A

Solution architecture

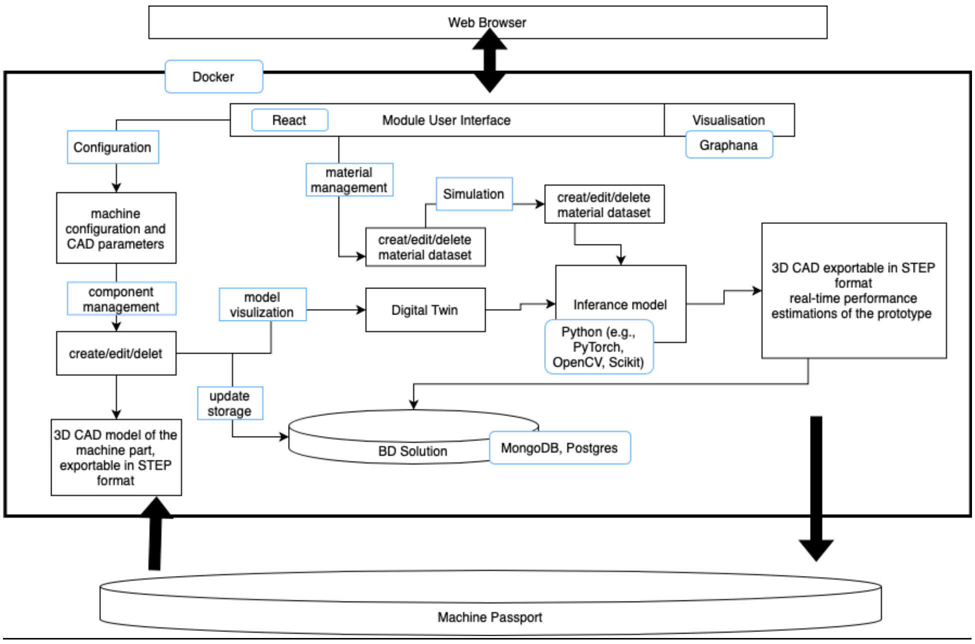


Figure 48. MDG implementation architecture.

Details about architecture
The architecture for the machine synthetic data generator involves several components and technologies. The backend development will primarily be done in Python, which is a widely used language in AI and machine learning applications, offering extensive libraries and frameworks. PyTorch, an open-source AI framework, will be utilized for building and training deep learning models. Additionally, scikit-learn, another powerful library, provides tools for data preprocessing, sampling, and model training, offering a range of machine learning algorithms. For data analysis and processing, Pandas will be employed, allowing for efficient manipulation and analysis of data. Simulation will be facilitated using digital twin technology, and depending on the specific use case, there may be integration with simulation software such as ANSYS, COSMOL, or OpenFOAM. In terms of data management, structured databases like MySQL or non-structured databases like MongoDB will be used to efficiently store and retrieve data. Lastly, for monitoring and visualization purposes, Grafana can be employed to provide real-time monitoring and visualization of the generated data. Overall, this architecture incorporates a variety of technologies and tools to ensure effective data generation, analysis, simulation, and management for the machine synthetic data generator.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/MDG.html

5.5.3 CAx (CAx Addon)

Usage Viewpoint
Description
Environment configuration: AI-CAx user (operator) configures the parameters for the AI-CAx module. These parameters are mainly the parameters of the AIDEAS solution that AI-CAx is integrating (e.g., AI-MDG). **Deployment:** The operator uses the AI-CAx addon to initiate Machine-2-Machine (M2M) communication between the AI-CAx module, the AIDEAS solution that the AI-CAx addon is integrating (e.g., AI-MDG), and/or the external solutions (e.g., external simulation tools).
Use Model

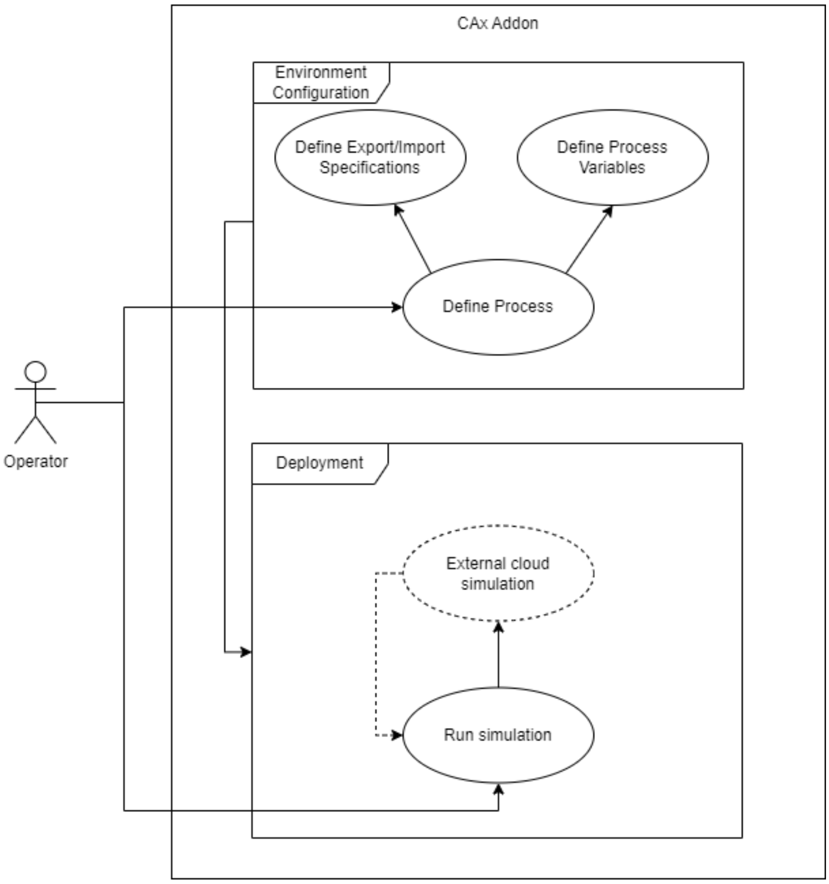


Figure 49. CAx Use Model.

Functional viewpoint	
Description	
What	CAx component provides Machine-2-Machine (M2C) communication between the AI-MDG component and the external tools (e.g., external simulation tools).
Who	Machine designers. Process optimization engineers. CAx developers
Where	Enterprise layer
Why	Provides M2C communication (e.g., via API calls) between existing CAx tool (CAx addon), AIDEAS-developed components (e.g., AI-MDG) and external tools.

Functional diagram

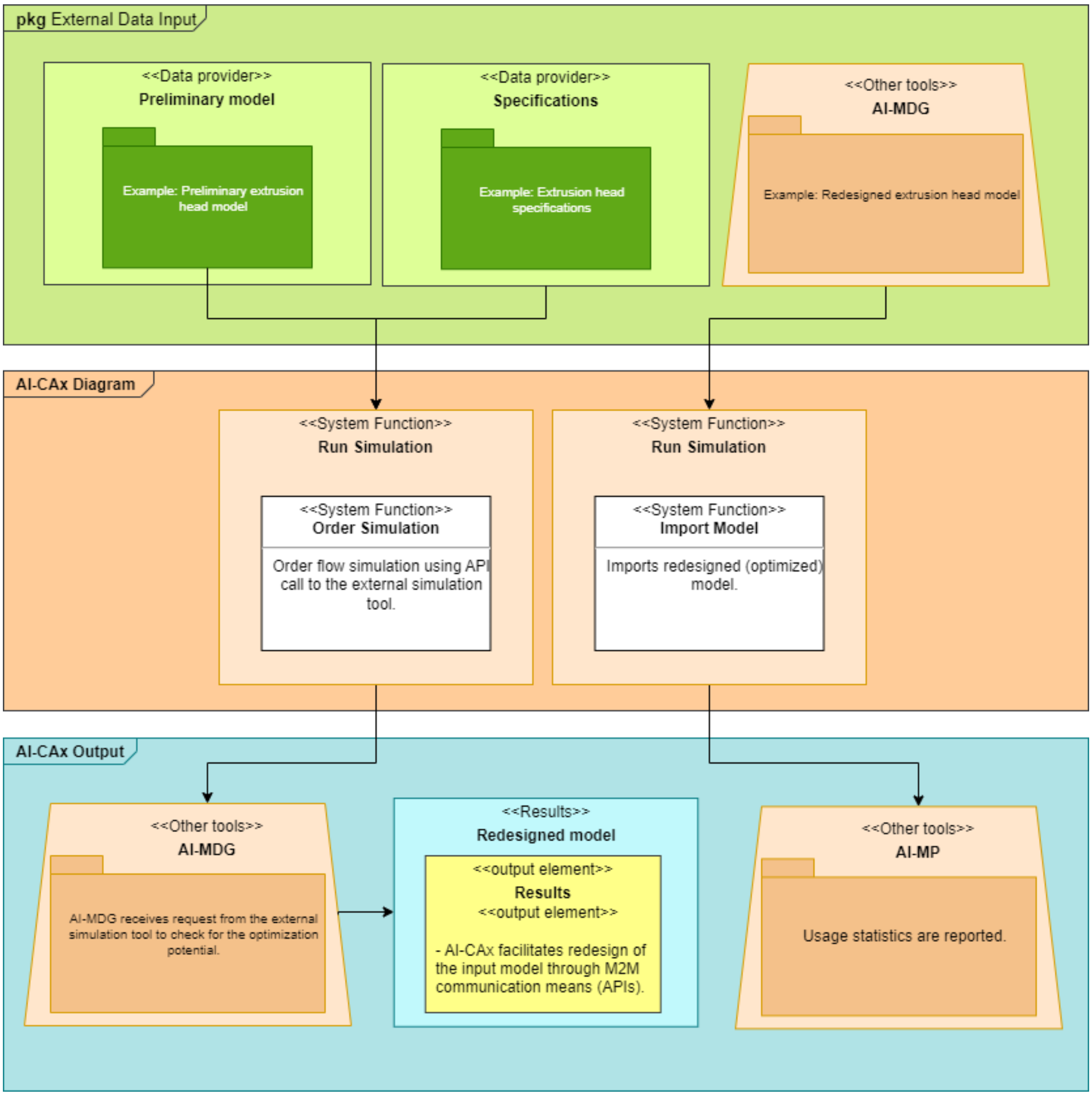


Figure 50. CAx functional diagram.

Implementation Viewpoint

Description of implementation Component

AI-CAx provides support for the integrations of AIDEAS AI-based solutions to existing CAx solutions.

Technical Description of its Components

Dependencies	Development Language: Depends on the chosen CAx solution and addon development requirements imposed by the CAx solution. Libraries: Chosen CAx SDK (if available). Container: Depends on the chosen CAx tool requirements. Database need: No data management is envisioned for AI-CAx.
Interfaces	User Interface: No specific development of user interfaces is planned. The CAx module will be used for Machine-2-Machine (M2C)

	communication. The user interfaces of the selected CAx and AIDEAS solutions using AI-CAx will be used to demonstrate the usage of AI-CAx. To be specified in later phases of AI-CAx development. Synchronous/Asynchronous Interface: Depends on the chosen CAx and AIDEAS solution to be using the AI-CAx module. To be specified in later phases of AI-CAx development. Network/Protocols: To be specified in later phases of AI-CAx development. Data Repository: No data management is envisioned for AI-CAx.
Requires	Other N/A Solutions: N/A

Solution architecture

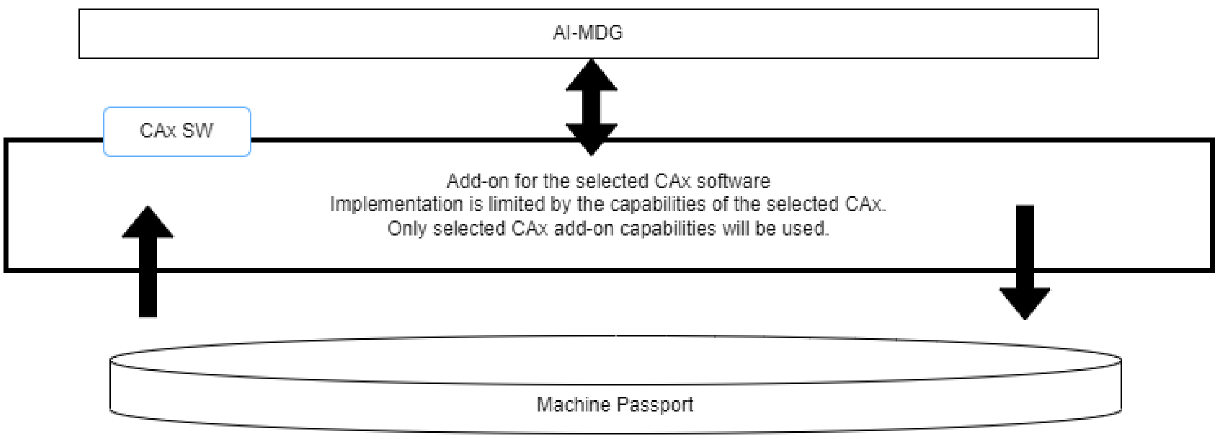


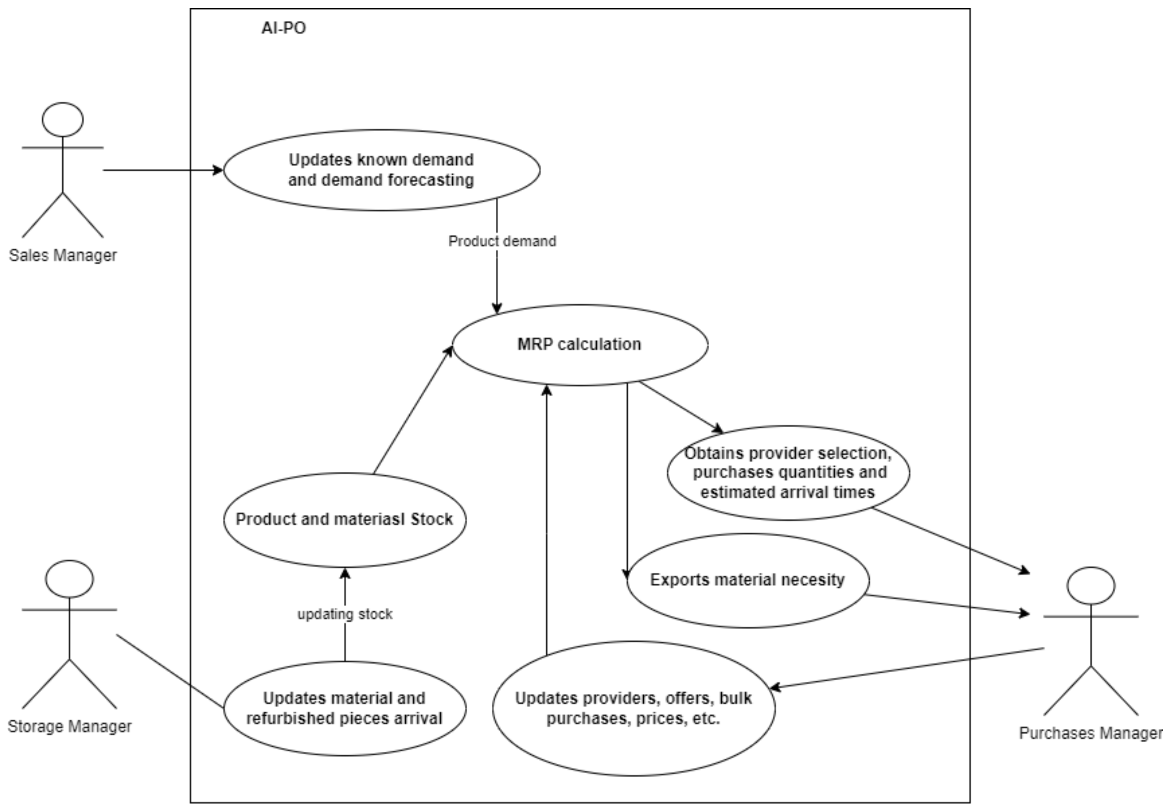
Figure 51. CAx implementation architecture.

Details about architecture

AI-CAx component provides Machine-2-Machine (M2C) communication between the AI-MDG (only AIDEAS solution that exposed the need for AI-CAx) component and the external tools (e.g., external simulation tools). The implementation of the CAx addon will largely depends on the i) chosen CAx software (e.g., SolidWorks) and the requirements imposed by CAx add-on development capabilities and limitations of the chosen CAx, ii) AI-MDG solution limitations to be using AI-CAx module. CAx software will be again selected by the requirements of the AI-MDG, while we will need to ensure that the chosen CAx software supports add-on development and its freely available for development purposes or a license provided by either pilots or AI-MDG solution developers.

More information here: https://viewpoints.aideas-srv.cigip.upv.es/CAx.html

5.5.4 PO (Procurement Optimiser)

Usage Viewpoint
Description
The **MRP calculation** is an **iterative process**. The process is initiated by **the purchasing manager.** In the first step the solution obtains the information on the **current stock** status that must be updated, this includes the **future arrivals** of **purchased products** and the arrival of **remanufactured products.** Another piece of information needed to calculate the MRP is the **known demand** with delivery dates and the **forecast of future demand,** which are provided and updated by the **sales manager.** From this information, the solution will derive the **production requirement with delivery dates.** The solution also has access to the list of suppliers that contains the procurement time and the quantity of products that each supplier can deliver in a procurement window. In addition to this, offers for bulk purchases can be added to each provider's information. With all this information, the application will calculate the **MRP** and **select the best suppliers** for each product needed or select remanufactured products from stock, considering an **optimisation objective** selected by the purchases manager. When unexpected events occur, such as a purchased product not arriving on time, a change in demand (cancellation of orders or arrival of new orders) or offers are received from suppliers, the solution will recalculate the MRP and send it to the purchasing manager the new status of the purchasing needs and supplier selection.
Use Model
 **Figure 52.** PO Use Model.

Functional viewpoint	
Description	
What	This component's main feature is to calculate and update the material requirement planning considering different providers' bulk sales prices and delivery times. Also, this MRP will be calculated and updated considering the use and arrival of refactored material and parts.
Who	Sales manager. Storage manager. Purchases Manager.
Where	Edge of the machine.
Why	One of the most relevant objective referents to this project is the use of refactored or refurbished materials as part of the manufacturing chain and the capability of generating an MRP optimized for different objectives (like, accomplishing all delivery dates or selecting the cheapest provider).
Functional diagram	

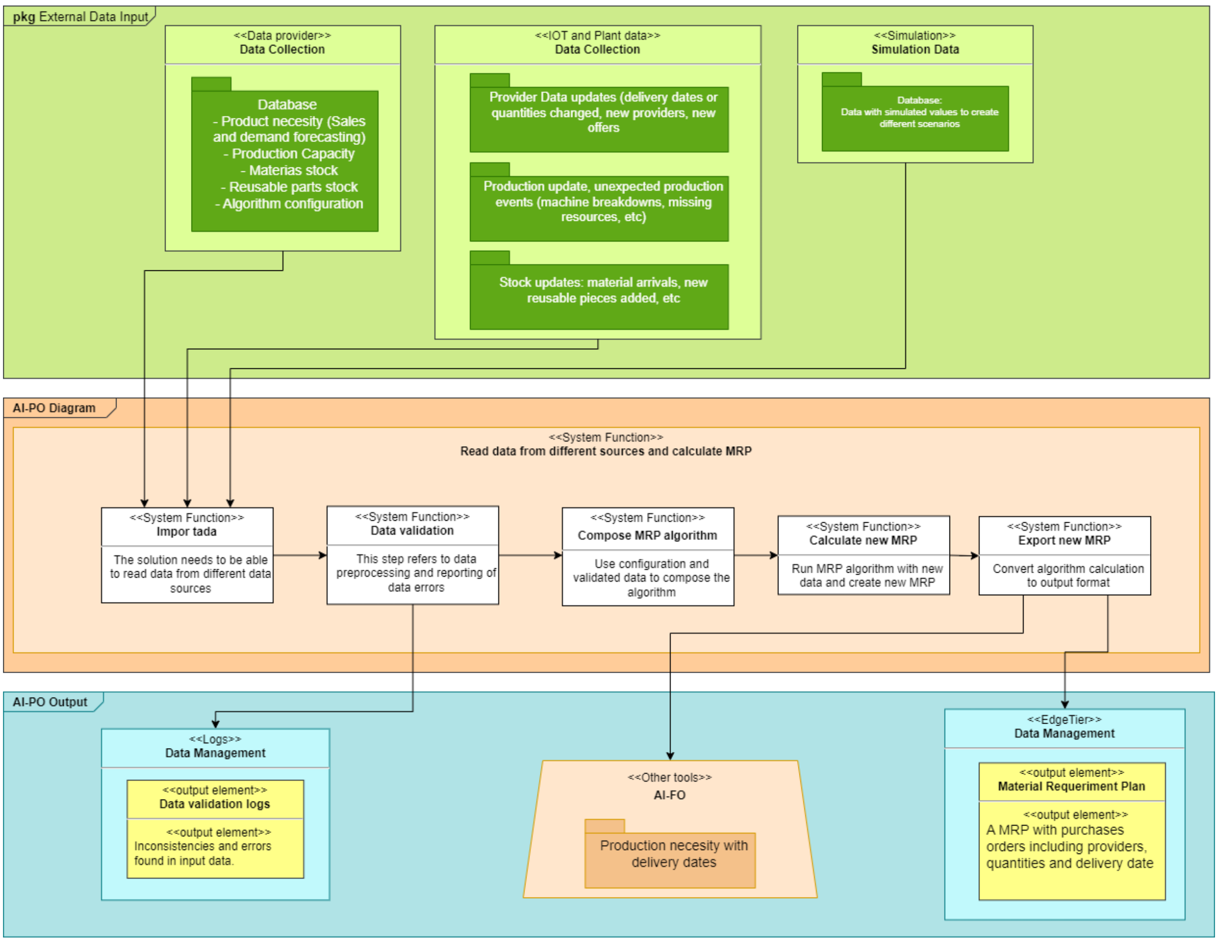


Figure 53. PO functional diagram.

Implementation Viewpoint	
Description of implementation Component	
AI-PO will receive data from multiple sources, like ERP direct connections by API calls, SQL databases and non-SQL databases like SQL Server, Oracle, MongoDB, etc. Also, other sources of data will be considered as excel files, CSV files, JSON messages, etc. The source and format of data will depend on the pilot, but the solution will provide at least standard data connectivity to SQL databases and methods to manage information using JSON-formatted messages. Calculation of MRP and provider selection will require up-to-date information. From the BoM to real-time stock updates, the information will come from different sources. As mentioned in the usage point of view subsection the information necessary to calculate the MRP should also include known demand, demand forecasting, providers' delivery capacities (in time and quantity) and providers' prices and bulk prices. AI-PO application is designed to work as a standalone service, connected to different systems and software present inside the plant. The application will also provide standard security by requiring authenticated connections through JWT. Connection to and from the AI-PO solution will be made through API calls. **Software requirements** AI-PO solution requires .net runtimes to work and provides a connection by means of an API, if necessary, it also can provide a gRPC connection, this should be studied on each pilot. Initially, only API access will be developed. AI-PO will be delivered in a docker container already configured to run. Because of this docker, the infrastructure to run docker containers is required to be present in the implantation place.	
Technical Description of its Components	
Dependencies	Development Language: .NET, C# Libraries: .net runtime, email parser Container: Docker Database need: depending on pilot, SQL Server or similar
Interfaces	User Interface: Depending on pilot, REACT or similar Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: SQL Server or similar (eg MariaDB or PostGres)
Requires	Other N/A Solutions: N/A

Solution architecture

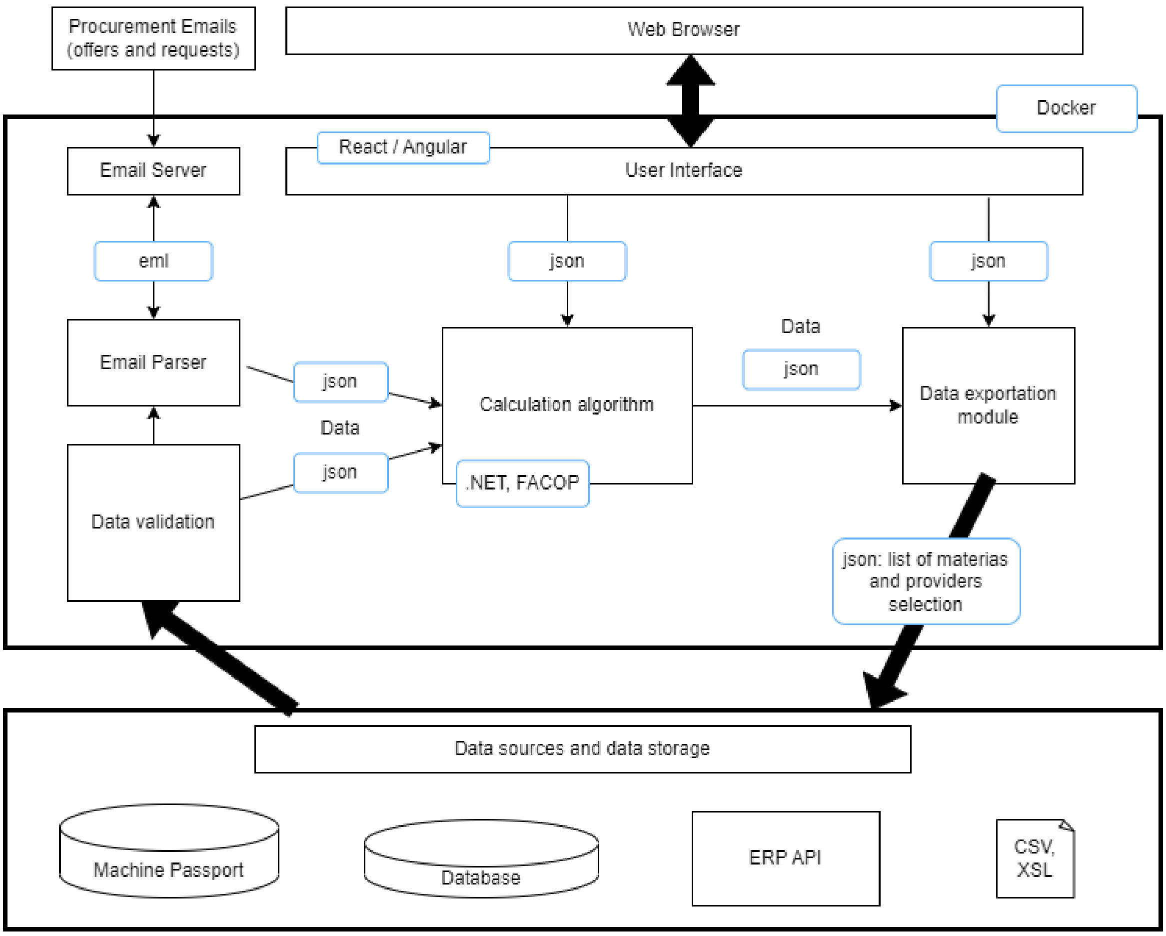


Figure 54. PO implementation architecture.

Details about architecture

The procurement optimization (PO) component uses mainly the FACOP framework which is composed of a series of libraries developed at ITI. These are general optimization libraries centred on heuristics and meta-heuristics. These libraries are developed in C#, in this project MRP calculation libraries will be developed and added to FACOP components.

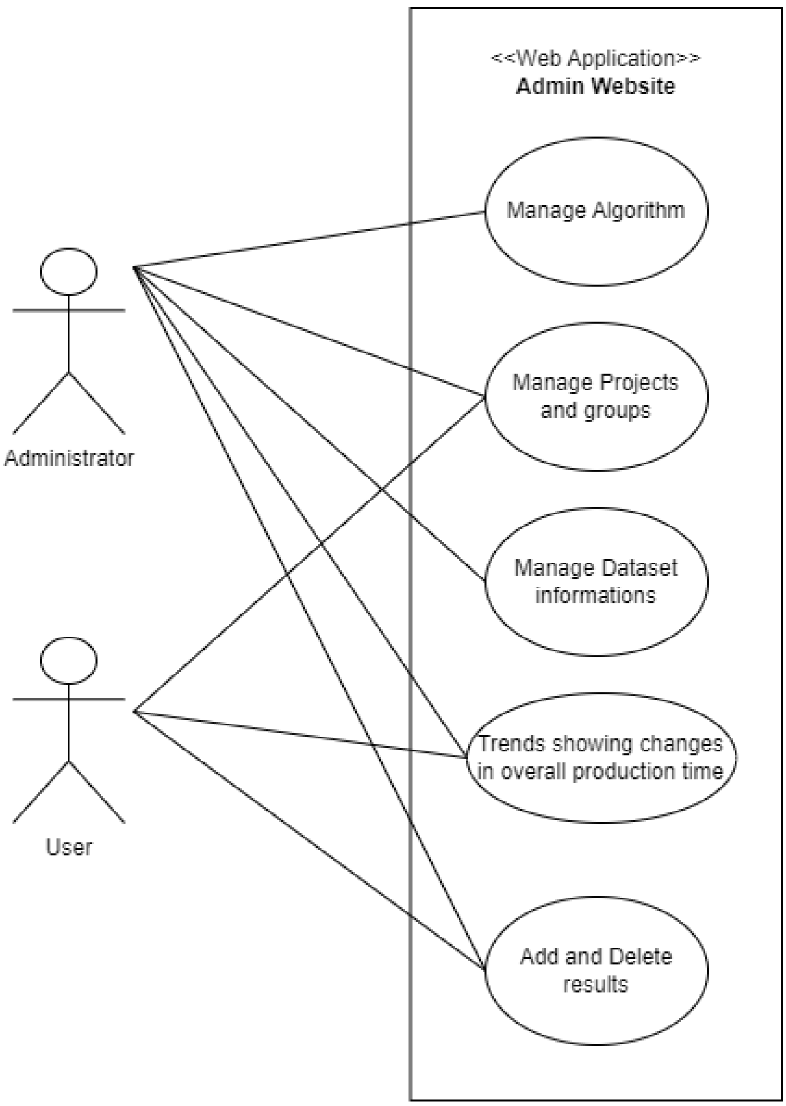
.NET is fast and reliable and widely used in all types of software but also deeply related to industry software. All the libraries used in FACOP and PO are part of the .NET framework or were developed as part of FACOP.

The PO solution will be configured to work inside a docker container, this allows flexibility, stability and scalability to the solution.

A common interface will be developed in REACT or a similar platform. This generic interface will be adapted depending on the pilot. In some cases, a user interface will not be necessary because the results of the PO solution will be exported directly to other tools (like ERP) already in use on the pilots. The connection between the PO solution and the environment will be done through a Restful API using the https protocol.

More information here: https://viewpoints.aideas-srv.cigip.upv.es/PO.html

5.5.5 FO (Fabrication Optimiser)

Usage Viewpoint
Description
The engineer in charge of production will have to set the parameters necessary for the algorithm to work, such as machine types, article types, and other information necessary for accurate scheduling. He will also be responsible for managing the data in the database and will be responsible for periodically updating the algorithm to train it with the latest available data. For this task, he/she will need access to data from the MES, PLC, PLM, etc. At each scheduling launch, the user shall be able to view the results in graphical (Gantt chart) and tabular form. The results will be saved automatically in a database. When unforeseen events occur, such as the failure of a machine, the manufacture of non-conforming parts, lack of material for processing, etc., the scheduling must be re-scheduled in the shortest possible time in relation to the event that occurred.
Use Model
 **Figure 55.** FO Use Model.

<table>
<tr><th colspan="2">Functional viewpoint</th></tr>
<tr><td colspan="2">Description</td></tr>
<tr><td>What</td><td>Through this tool obtains rectification parameters for the manufactured item to be compliant in a single re-machining step.</td></tr>
<tr><td>Who</td><td>Production manager.</td></tr>
<tr><td>Where</td><td>Enterprise layer</td></tr>
<tr><td>Why</td><td>The aim is to obtain the reprocessing parameters of the artefact in a single step to avoid further processing.</td></tr>
<tr><td colspan="2">Functional diagram</td></tr>
<tr><td colspan="2">For Pilot 1</td></tr>
<tr><td colspan="2">

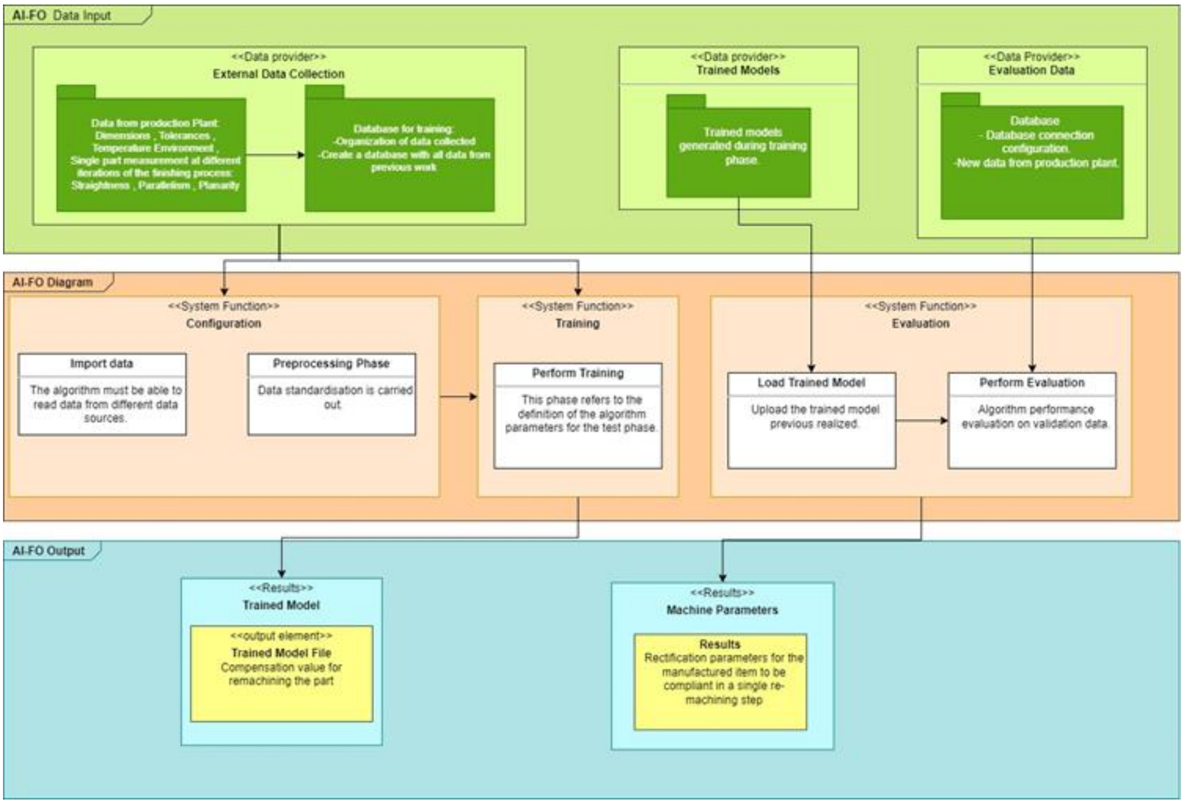


Figure 56. FO functional diagram (Pilot 1).

</td></tr>
</table>

For Pilot 3 and Pilot 4

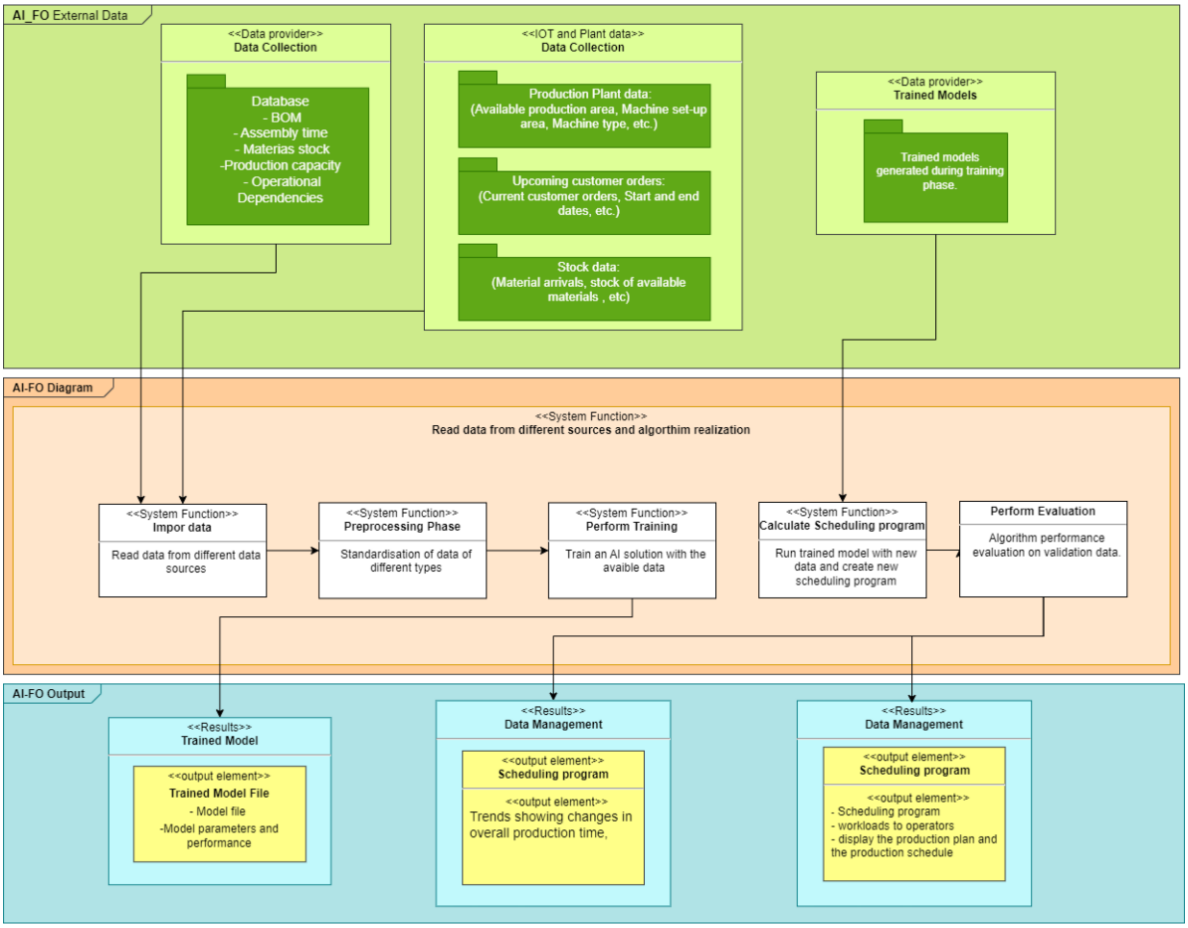


Figure 57. FO functional diagram (Pilot 3 and 4).

Implementation Viewpoint	
Description of implementation Component	
AI-FO is for the optimization of the production process and scheduling program.	
Technical Description of its Components	
Dependencies	Development Language: - Python Libraries: Sklearn, Pyomo, Pandas, Numpy Container: Docker Database need: MySQL
Interfaces	User Interface: Yes, WordPress Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MySQL
Requires	Other N/A Solutions: N/A
Solution architecture	

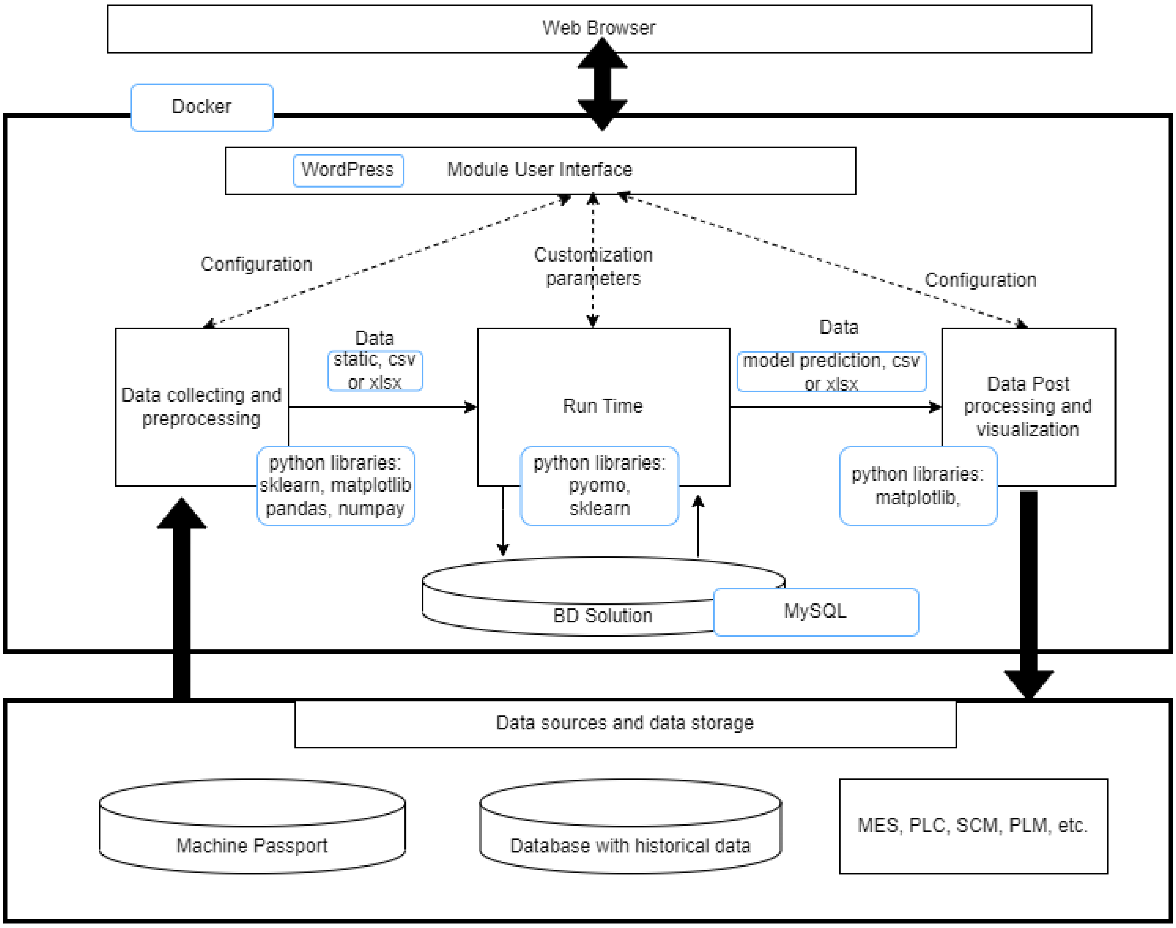
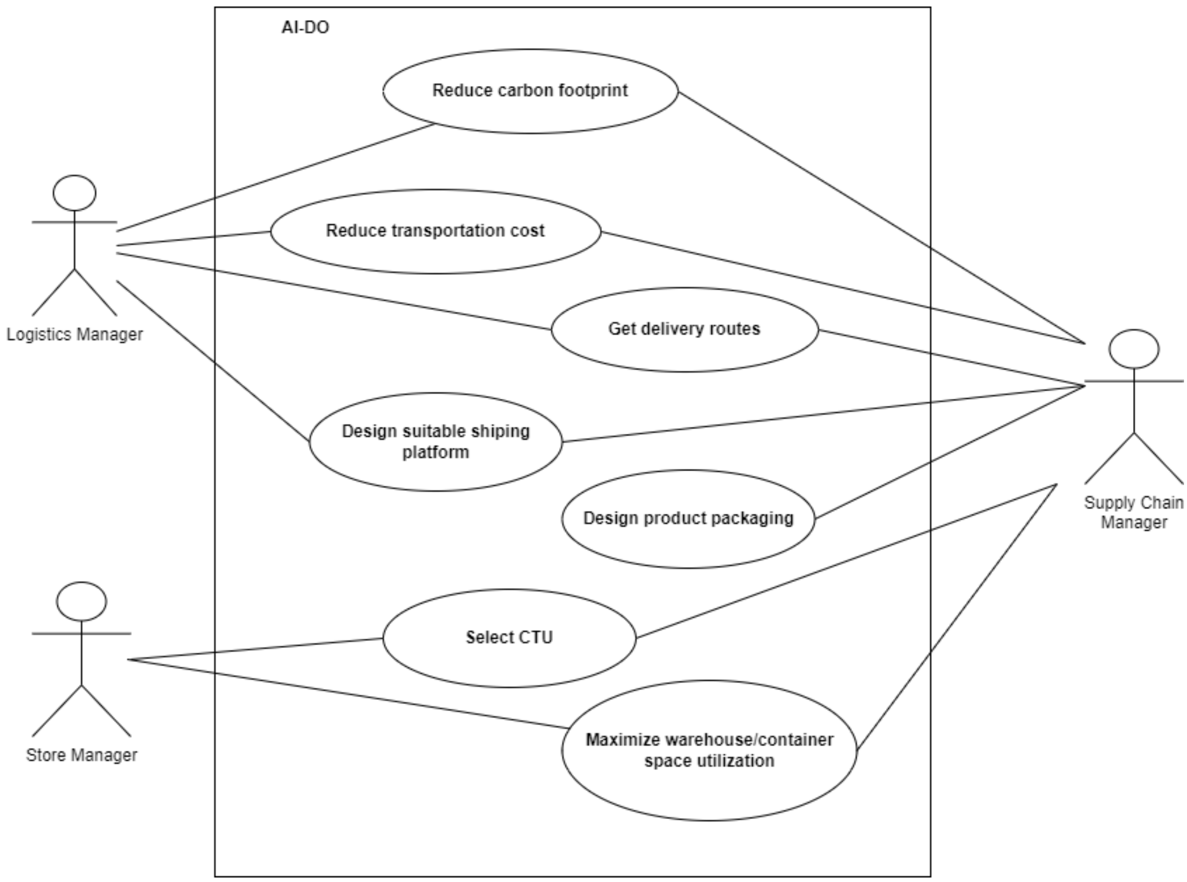


Figure 58. FO implementation architecture.

Details about architecture
The primary development language for the FO is Python due to its undisputed usefulness for data processing and machine learning. Will be used Pandas and Numpy for data handling and Sklearn for the data pre-processing phase and for model training. Pyomo will perhaps be used for the realisation of the mathematical model of the scheduling programme (if a mathematical model is preferred). Will be used WordPress for the realization of a user interface. A RESTful API will be used to simplify communication between the backend and frontend, using HTTPS protocols to ensure the secure transmission of data. A MySQL database will house the actual data. In order to speed up the deployment process and ensure the portability of the software, Docker, a platform for grouping all the components and dependencies needed to ensure efficient software execution, will be used.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/FO.html

5.5.6 DO (Delivery Optimiser)

Usage Viewpoint
Description
The main actors benefiting from the solutions provided by the delivery optimizer are the logistics manager, store manager, and supply chain manager. Through the different solutions offered by the AI-DO, the complete process from packaging a machine/machine part to either its storage or delivery to the customer, can be facilitated by AI algorithms. An example scenario is where the supply chain manager can use the AI-DO to predict parameters to facilitate packaging design, these parameters can include for example, packaging size, packaging material, fragility etc. Furthermore, once the packaging is done, the store manager can also use the solutions offered by AI-DO to get a layout design to either store the package in the warehouse or place it in the Container Transport Unit to send it off for delivery. Once the product is ready for delivery, the logistics manager can also use the solutions offered to get predicted parameters such as Estimated time of arrival, transportation cost, best route, and CO_2 consumption. Based on these predictions, the logistics manager can choose delivery options according to the needs and restrictions.
Use Model
 **Figure 59.** DO Use Model.

Functional viewpoint	
Description	
What	Suggests optimal packaging for the machine part inputted to the component, including packaging material, package thickness and need for extra protection.
Who	Storage manager, Logistics manager, Supply chain manager.
Where	Edge Tier (at client level).
Why	The packaging optimizer aims to improve the packaging used for machinery parts. It will help in quickly finding the best possible packaging (packaging material, packaging thickness), for a machine part, thus improving the package safety and reducing packaging cost and packaging waste over alternatives such as manual packaging.
Functional diagram	

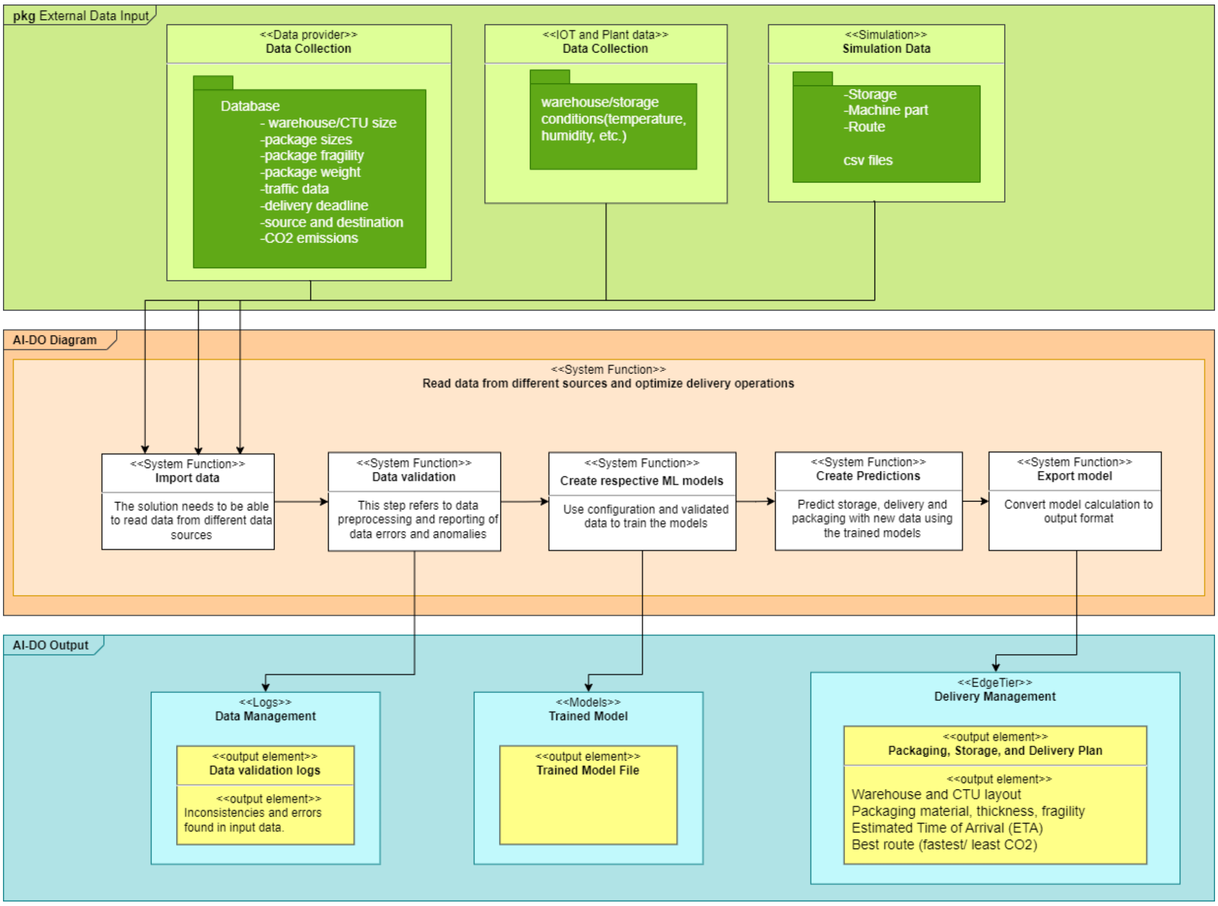


Figure 60. DO functional diagram.

Implementation Viewpoint	
Description of implementation Component	
AI-DO is for the optimization of machine packaging and delivery	
Technical Description of its Components	
Dependencies	<u>Development Language</u>: - Python <u>Libraries</u>: Pymoo, sklearn <u>Container</u>: Docker

	Database need: MongoDB, Postgres
Interfaces	User Interface: Yes, REACT Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MongoDB
Requires	Other N/A Solutions: N/A

Solution architecture

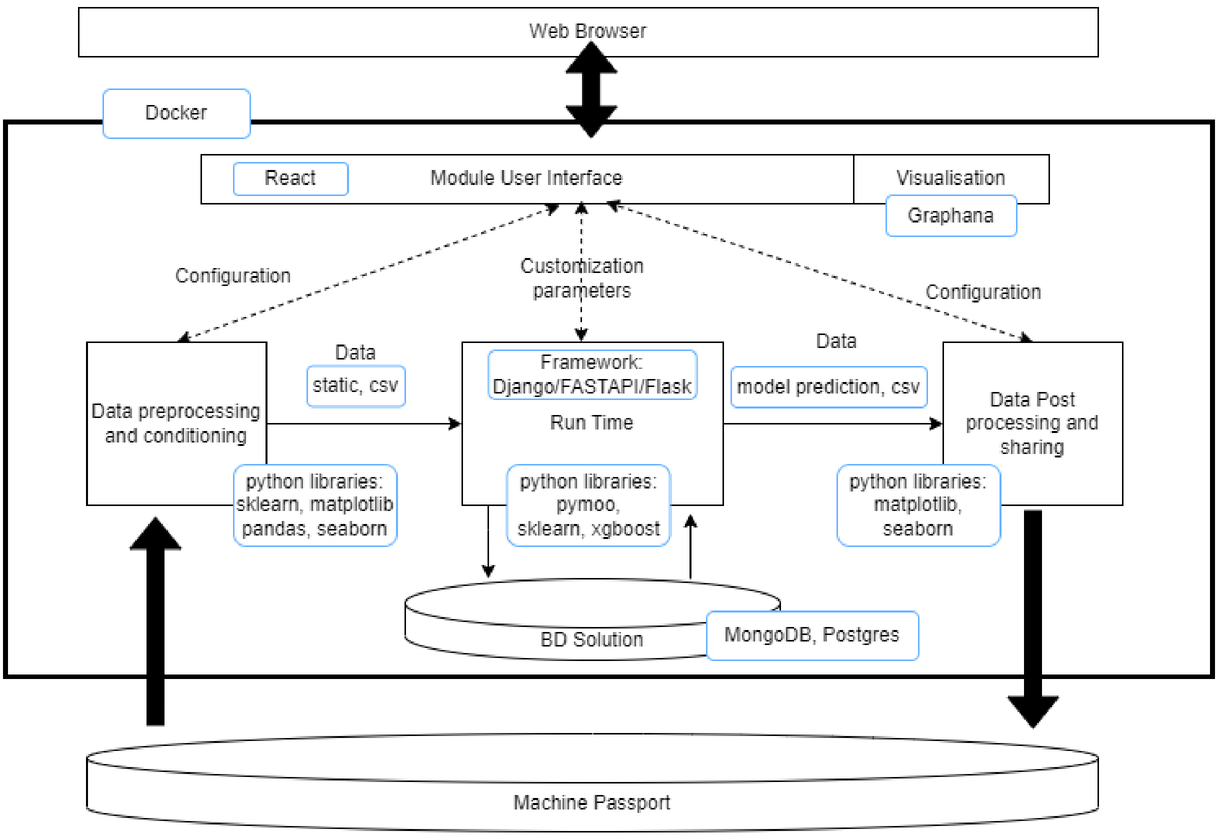


Figure 61. DO implementation architecture.

Details about architecture

The primary development language for the delivery optimizer is Python due to its undisputed usefulness for data processing and machine learning, while the library which will primarily be used is sklearn for the purpose of data preprocessing and cleaning and also for model training. Pymoo library will be used for optimization as it facilitates multi-objective optimization. For containerization, the docker platform will be used. We also plan on using MongoDB for our database needs mainly due to its flexibility and ease of use and simplicity. Furthermore, for the frontend, we will create the user interface in REACT, simply due to its widespread adoption and familiarity with our inhouse expertise. We will use Restful APIs and HTTP and HTTPS as the network protocol.

More information here: https://viewpoints.aideas-srv.cigip.upv.es/DO.html

5.5.7 MC (Machine Calibrator)

Usage Viewpoint

Description

The main interveners in the AI-MC solution are the **Machine Installation Specialist** and the **Engineer**. The process is initialized by the **Machine Installation Specialist**, which first enters the **machine's initial configuration** parameters, as well as its calibration settings. Afterwards, the solution includes a **data acquisition** module, which has the mission of receiving the data from the machine's initial configuration as well as from the calibration preparation. Then, the **Machine Installation Specialist** and the **Engineer** must coordinate their work, to build a model that will be trained with the data obtained from the calibration process performed by the **Machine Installation Specialist**, thus obtaining the **Calibration Configuration** (validated by the engineer's guidelines), which has a parameterization profile best suited to each situation that is used to assist the calibration task performed by the **Machine Installation Specialist**. The solution, on the other hand, has a decision structure that monitors the effectiveness of the calibration, being this information used as a feedback variable in the system, to assist in the process of producing the calibration profile.

Use Model

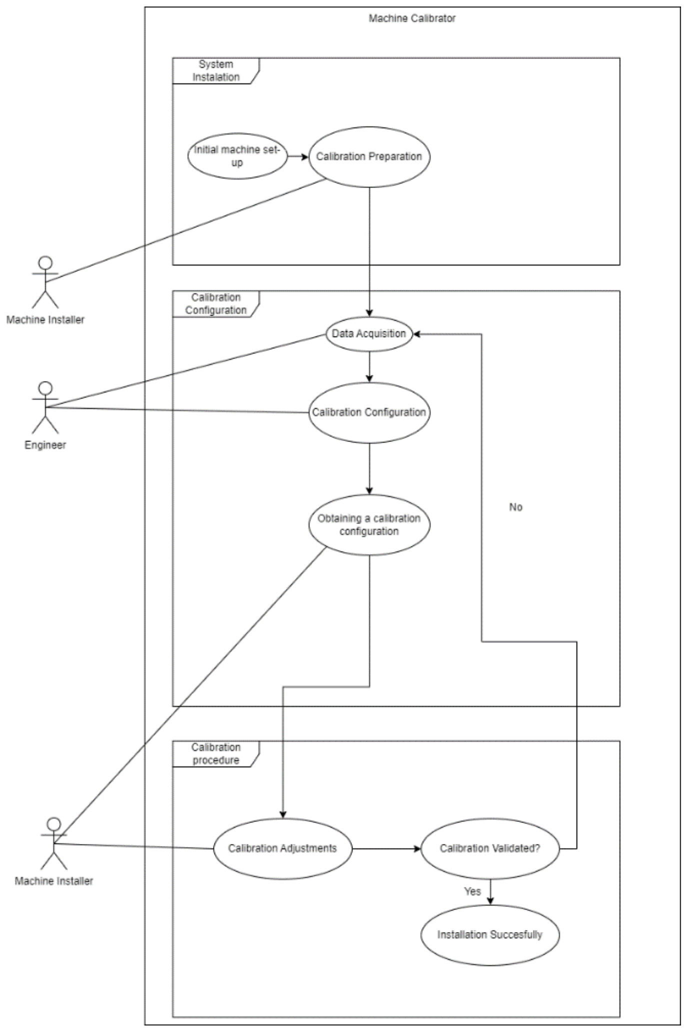


Figure 62. MC Use Model.

Functional viewpoint	
Description	
What	Assess machine installation conditions and provide calibration parameters. For external input data, the solution will use the cartesian coordinate of the working table, collecting the cartesian points of each corner of the table are used. The system must receive, prepare and filter (if necessary) the received data. The data must then be validated against limits or constraints imposed by the manufacturer. Next, this data is used by the solution to create a model calibration assistance algorithm. Subsequently, the axial coordinate data is used by the algorithm to monitor and assist the monitoring process in real-time. Regarding output data, the system should detect data input errors or data inconsistency. On the other hand, it should show the calibration status of the various machines. Lastly, it has to provide the operators with an interface to assist in the calibration.
Who	Machine Installer, engineer.
Where	Edge Tier (at client level).
Why	Support the calibration of industrial equipment during the installation phase or when re-calibration is needed and reduce installation time and the skills required to calibrate the machine.
Functional diagram	

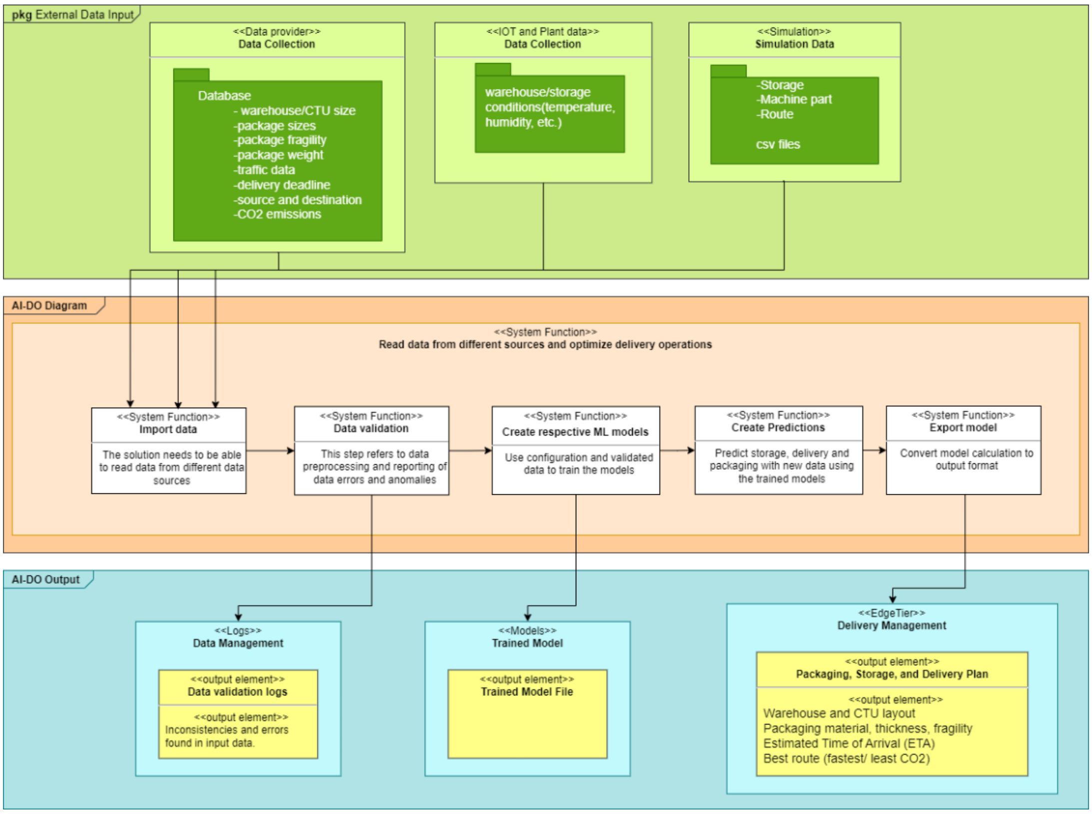


Figure 63. MC functional diagram.

Implementation Viewpoint
Description of implementation Component
AI-MC is a toolkit to support the operator in the calibration of the machines.
Technical Description of its Components

Dependencies	Development Language: Python Libraries: Python ML libraries Container: Docker Database need: SQL Server or similar (eg MariaDB or Postgres)
Interfaces	User Interface: REACT or similar Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: SQL Server or similar (eg MariaDB or Postgres)
Requires	Other AIDEAS Solutions: N/A

Solution architecture

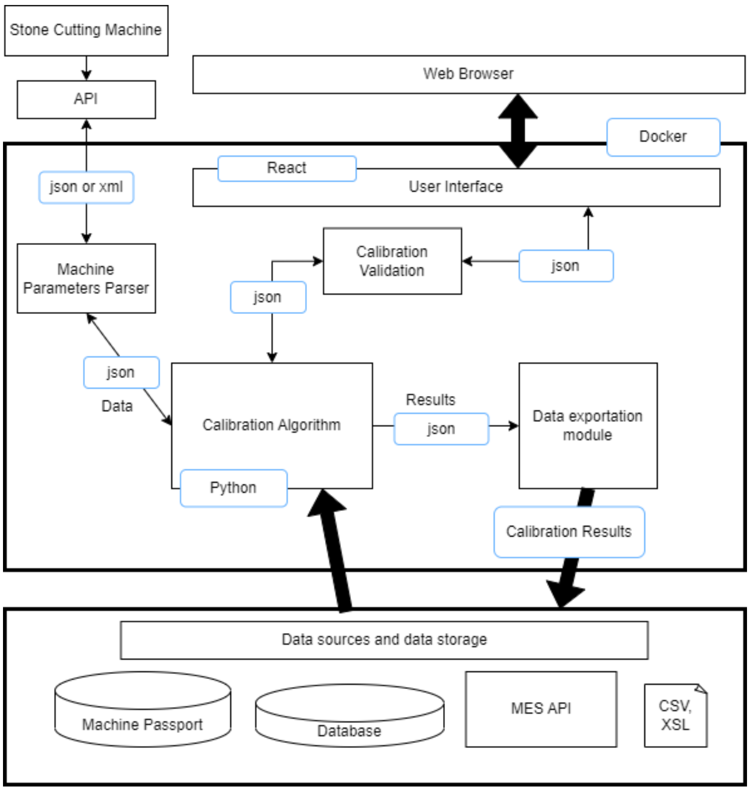


Figure 64. MC implementation architecture.

Details about architecture

The MC will leverage the data acquired from the machine operators on the initial equipment configuration for future parameter suggestions. The solution will be developed in Python, supported by extensive machine learning packages, using a SQL database in a Docker container environment. Data inputs/outputs will be consumed using a RESTful API and the calibration suggestions (as well as historical data) will be made available to the machine operators in a User Interface following the project REACT template.

More information here: https://viewpoints.aideas-srv.cigip.upv.es/MC.html

5.5.8 CE (Condition Evaluator)

Usage Viewpoint

Description

An initial step of configuration is necessary to define the scope where the Condition Evaluation will be deployed, and the machine to be monitored. For this task an engineer is required, so the machine is defined properly; these are the required tasks: i) first of all, the different machine components will be defined, that is, the different relevant zones of study in which the machine can be divided, ii) then, the different process variables present, such as temperatures, currents, pressures, speeds etc, and finally, iii) the association between process variables and components, meaning, which variables affect directly which component. As an additional step, it may be necessary to define working conditions such as which tool is currently being used, and the different processes performed or define the conditions that indicate that the machine is not idle or working.

Once the machine definition is completed, a model of the machine will be trained, for this task the supervisor and the operator have to work together. The supervisor will define the normal working conditions for each process variable of the study, that is, defining the thresholds in which the machine has proper behaviour. To train the model, a dataset is needed, obtained from a file or from a DB, as well as to define the desired algorithm and its parameters. Finally, the training process can be performed.

As the last step, the evaluation process will be performed by the operator. This process is a continuous task, where condition evaluation will be carried out to obtain the overall status of the whole machine and the status of specific components. The solution will give a score indicating if the machine is working properly or not. Every task performed by the operator can be performed by the supervisor and so on for the higher hierarchy users.

Use Model

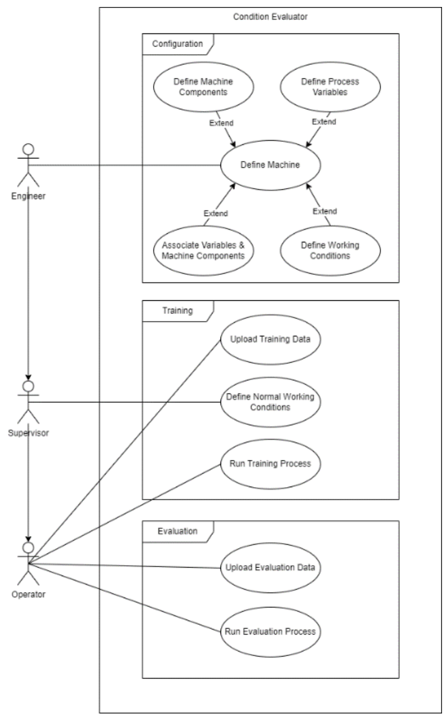


Figure 65. CE Use Model.

Functional viewpoint	
Description	
What	The main feature of this component is to define if the machine, in which is deployed, or in any of its components are working in good condition. Also, this evaluation could be computed in pseudo-real time.
Who	Process Engineer, C&I Engineer, Operator.
Where	Platform Tier.
Why	To monitor current working conditions.
Functional diagram	

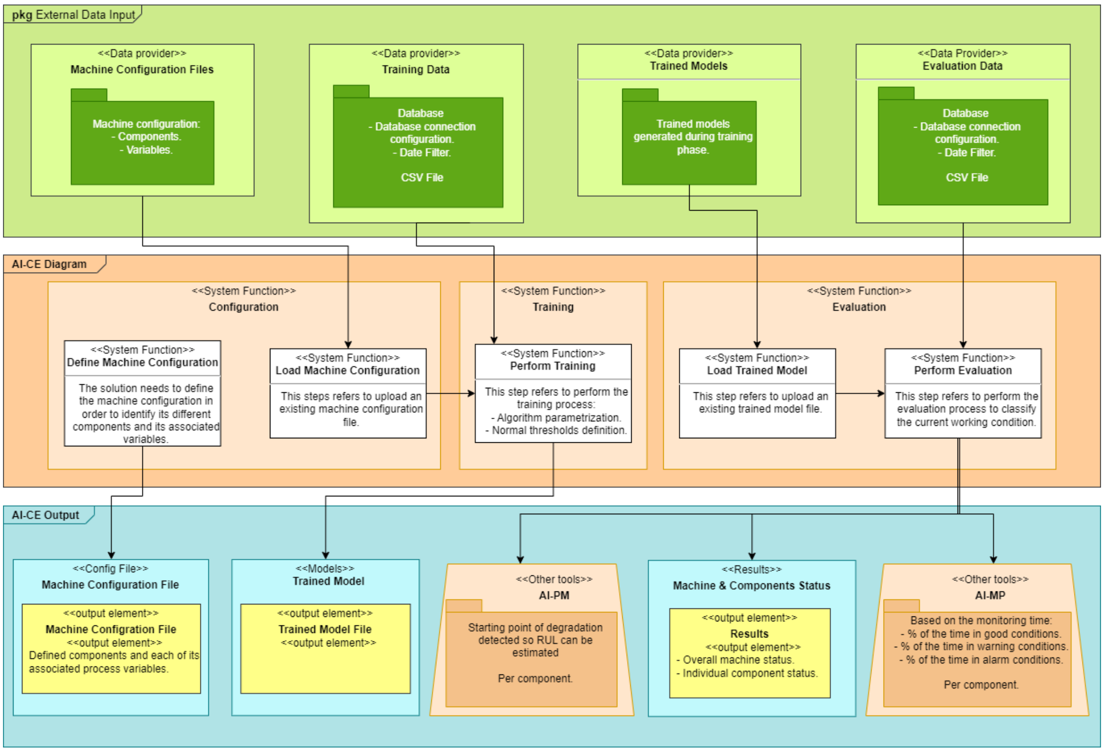


Figure 66. CE functional diagram.

Implementation Viewpoint	
Description of implementation Component	
AI-CE is a toolkit that performs condition evaluation at both machine and component levels.	
Technical Description of its Components	
Dependencies	Development Language: - Python Libraries: NumPy, Pandas, SciPy, Keras, Py Torch, TensorFlow Container: Docker Database need: MongoDB
Interfaces	User Interface: Yes, REACT Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS

	Data Repository: MongoDB
Requires	Other AIDEAS Solutions: N/A

Solution architecture

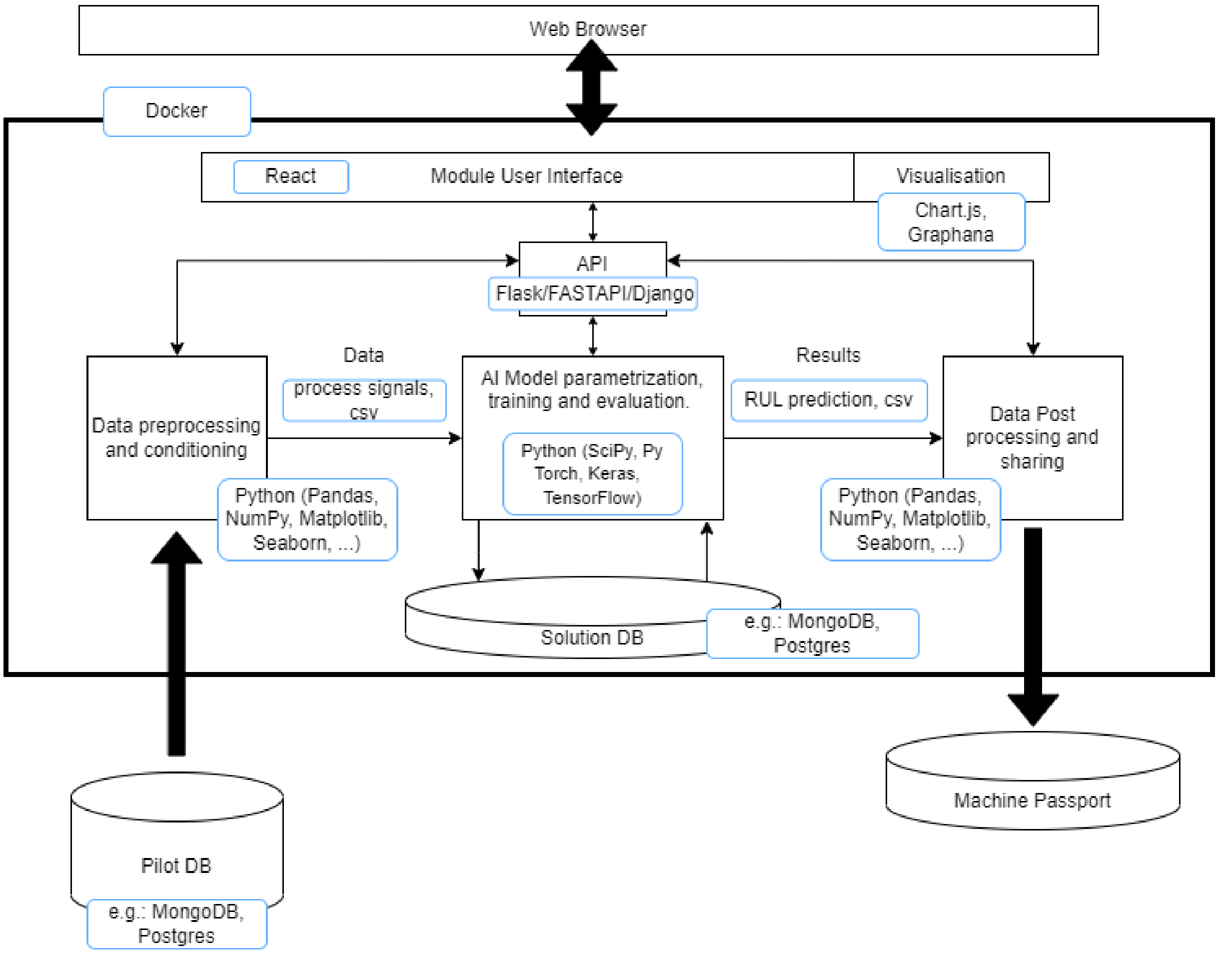


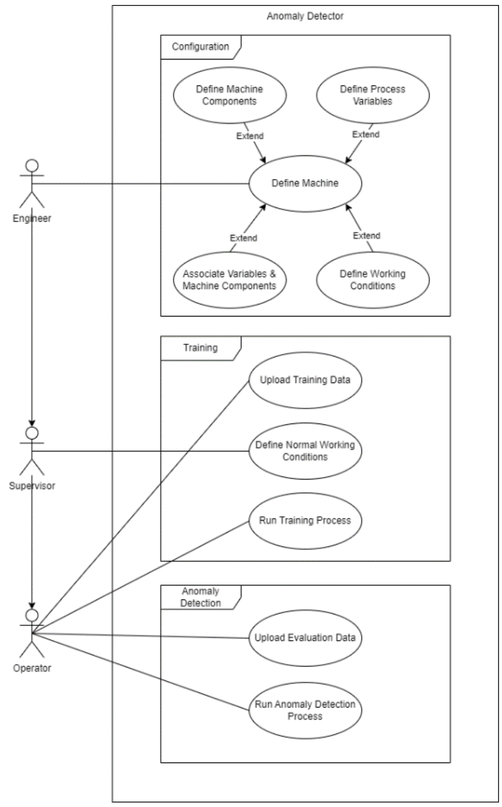
Figure 67. CE implementation architecture.

Details about architecture

AI-CE's backend will be developed in Python using the most common libraries used in data science and machine learning, such as NumPy for array and matrix processing, Pandas for data analysis and processing and SciPy, Keras, Py Torch and TensorFlow for training and evaluating machine learning models. **AI-CE**'s frontend will be developed in REACT, which is a JavaScript library, Redux will be used to manage the application state. Both backend and frontend, will be communicated over a RESTful API using HTTPS protocols. The API could be tested using tools such as Postman. Docker, which is a platform to build, deploy, run and manage containers, will be used to package everything the software needs to run.

More information here: https://viewpoints.aideas-srv.cigip.upv.es/CE.html

5.5.9 AD (Anomaly Detector)

Usage Viewpoint
Description
An initial step of configuration is necessary to define the scope where the Anomaly Detector will be deployed, and the machine to be monitored. For this task an engineer is required, so the machine is defined properly; these are the required tasks: (i) first of all, the different machine components will be defined, that is, the different relevant zones of study in which the machine can be divided, (ii) then, the different process variables present, such as temperatures, currents, pressures, speeds etc, and finally, (iii) the association between process variables and components, meaning, which variables affect directly which component. As an additional step, it may be necessary to define working conditions such as which tool is currently being used, and the different processes performed or define the conditions that indicate that the machine is not idle or working. Once the machine definition is completed, a model of the machine will be trained, for this task the supervisor and the operator must work together. The supervisor will define the normal working conditions for each process variable of the study, that is, defining the thresholds in which the machine has proper behaviour. To train the model, a dataset is needed, obtained from a file or from a DB, as well as to define the desired algorithm and its parameters. Finally, the training process can be performed. As the last step, the anomaly detection process will be performed by the operator. This process is a continuous task, where anomalies, if existing, will be detected. The solution will give a list of the last anomalies detected for the whole machine, as well as a list of the last anomalies detected per component. Every task performed by the operator can be performed by the supervisor and so on for the higher hierarchy users.
Use Model
 **Figure 68.** AD Use Model.

Description	
What	The main feature of this component is to detect if the machine, in which is deployed, or in any of its components an anomaly has been detected. This anomaly detection could be computed in pseudo real-time.
Who	Process Engineer, C&I Engineer, Operator.
Where	Platform Tier.
Why	To detect possible anomalies in the process.

Functional diagram

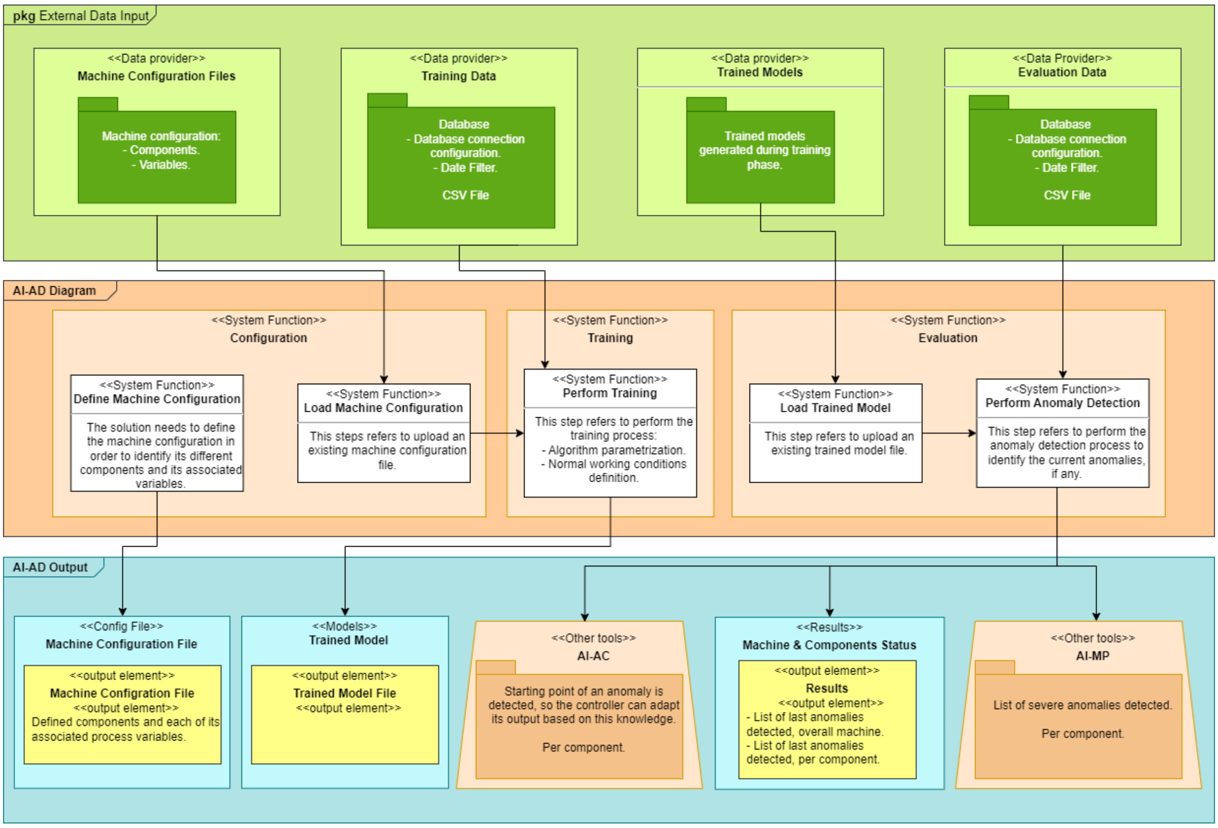


Figure 69. AD functional diagram.

Implementation Viewpoint

Description of implementation Component

AI-AD is a toolkit for anomaly detection at both machine and component levels.

Technical Description of its Components

Dependencies	Development Language: - Python Libraries: NumPy, Pandas, SciPy, Keras, Py Torch, TensorFlow Container: Docker Database need: MongoDB
Interfaces	User Interface: Yes, REACT Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS

	Data Repository: MongoDB
Requires	Other AIDEAS Solutions: AI-CE* (could be used as a trigger to know when an anomaly is first detected)

Solution architecture

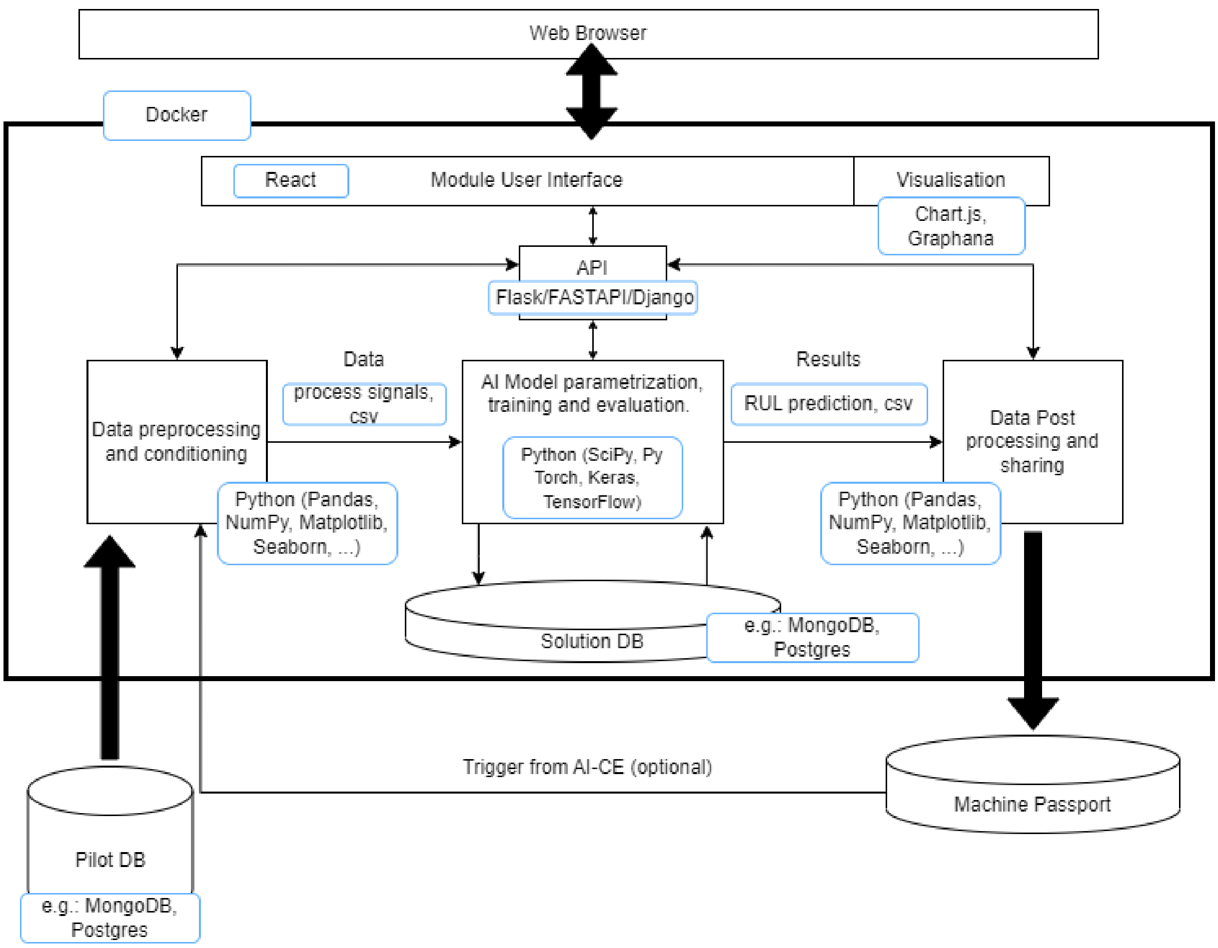


Figure 70. AD implementation architecture.

Details about architecture

AI-AD's backend will be developed in Python using the most common libraries used in data science and machine learning, such as NumPy for array and matrix processing, Pandas for data analysis and processing and SciPy, Keras, Py Torch and TensorFlow for training and evaluating machine learning models. **AI-AD**'s frontend will be developed in REACT, which is a JavaScript library, Redux will be used to manage the application state. Both backend and frontend, will be communicated over a RESTful API using HTTPS protocols. The API could be tested using tools such as Postman. Docker, which is a platform to build, deploy, run and manage containers, will be used to package everything the software needs to run.

More information here: https://viewpoints.aideas-srv.cigip.upv.es/AD.html

5.5.10 AC (Adaptive Controller)

Usage Viewpoint
Description
Environment configuration: • Define Process: which process are we going to control? We need a model that reproduces its behaviour. For this task the best scenario is that the engineer and the supervisor work together in the definition of it. So, the design criteria of the engineer and the performance criteria of the supervisor can be put together. • Define the algorithm corresponds to specify which will be the AC algorithm to use. Whereas the process variables refer to which variables are we about to control. Depending on the objective we may need different variables to control/monitor. **Training**: 1. Monitor Training Process: the supervisor should be responsible for monitoring the learning process. 2. In the definition of the reward function, the supervisor should ensure that the chosen cost function is adequate for the system. In every training, we aim to find the optimal conditions, and whether the process is optimal or not is defined by the reward function. 3. The process targets vary according to the process to be realized by the operator, as it changes along the supply chain. That is why the operator and supervisor should work together on the definition of the reward function. **Deployment**: • The monitorization of the process variables is a continuous task. Maybe the selected controller or model is not as suitable as thought and the system should be disconnected to prevent any damage. This should be identified by the operator to avoid any potential issues. • The evaluation of the performance is also continuous, the operator should also take care of how the system is performing. This should be carried out together with the supervisor, so the reward function, previously defined, is accomplished. The reward function is done by the two of them, therefore the performance evaluation too. • Once the learning is complete and successful, the controller parameters should be updated to those determined by the RL.

Use Model

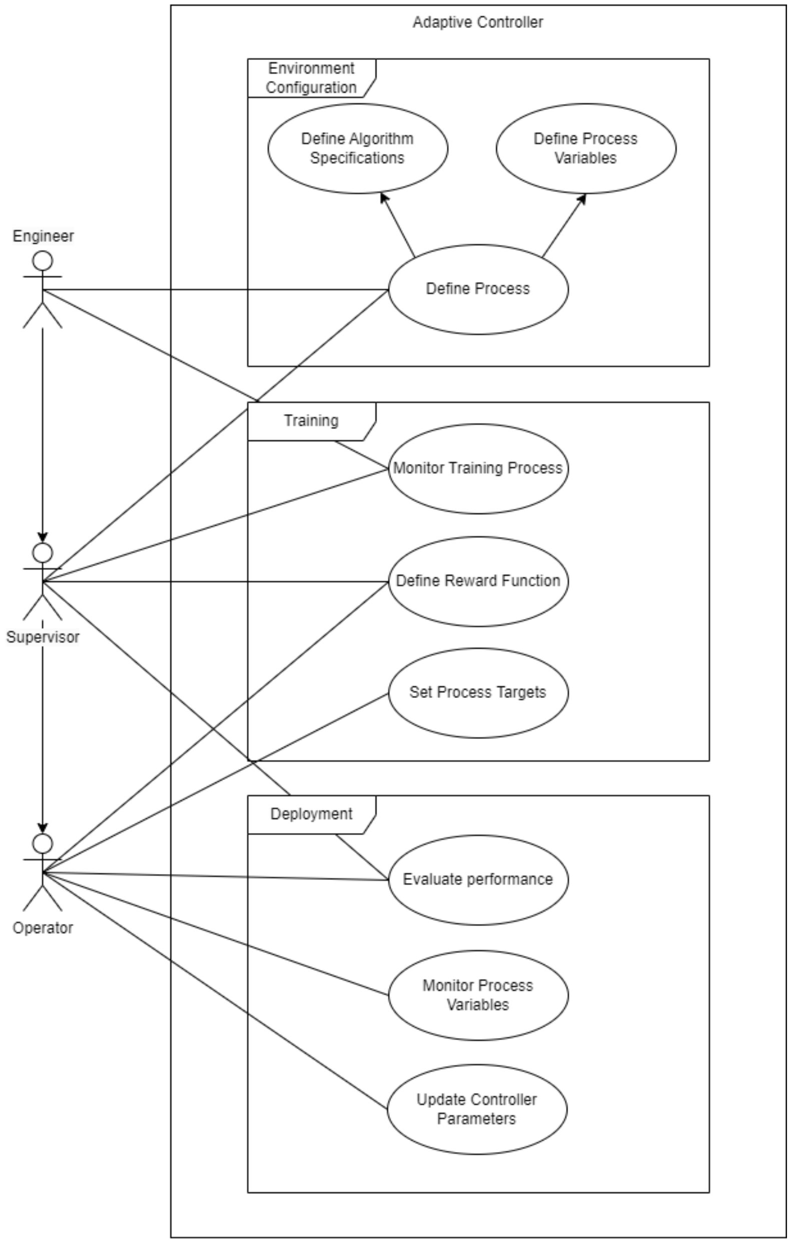


Figure 71. AC Use Model.

Functional viewpoint	
Description	
What	The main feature of this component is to adapt the controller to the conditions of the machine, so its capacity is kept at its best performance.
Who	Process Engineer, C&I Engineer, Operator.
Where	Edge Tier.
Why	Be able to control the machine under faulty scenarios

Functional diagram

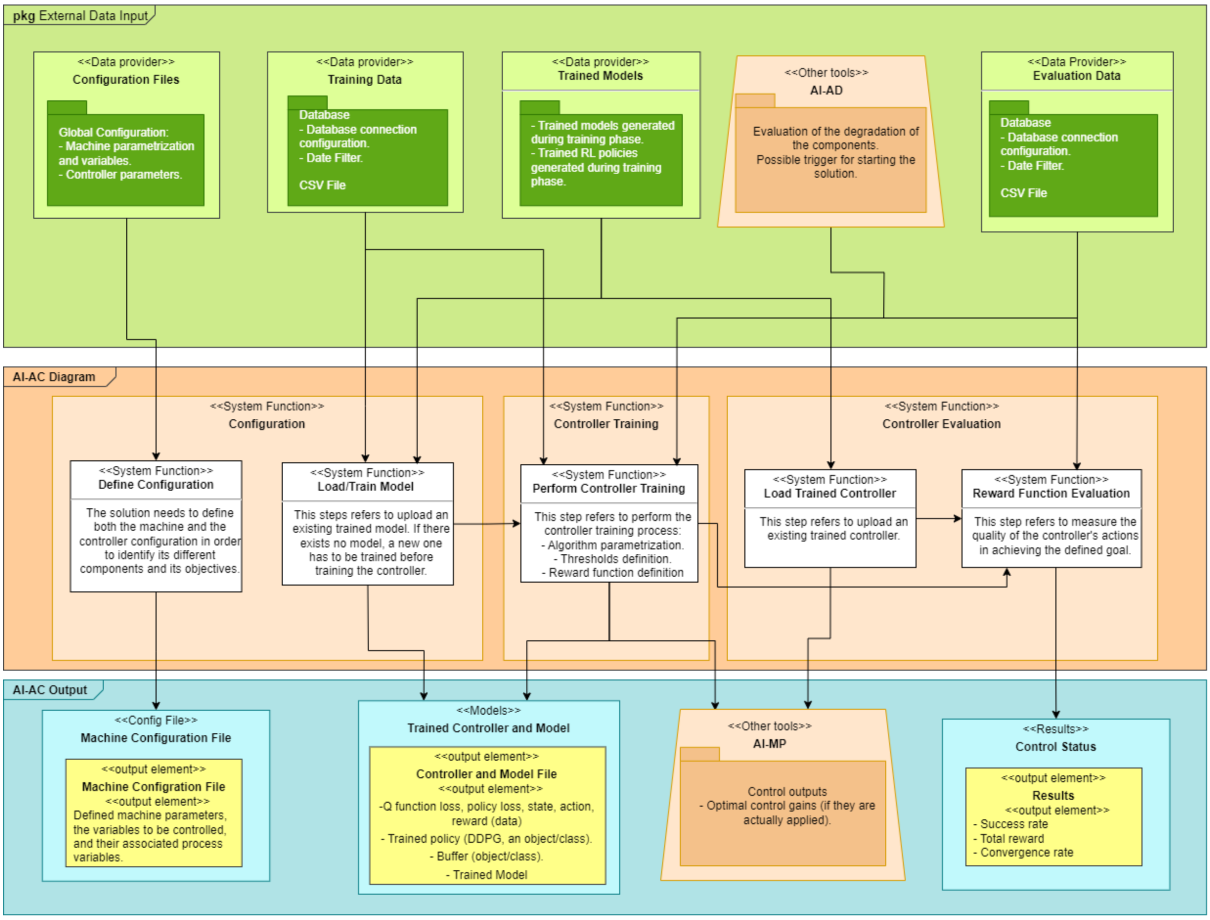


Figure 72. AC functional diagram.

Implementation Viewpoint

Description of implementation Component

AI-AC is a toolkit that adapts the controller in case of a faulty scenario.

Technical Description of its Components

Dependencies	Development Language: - Python Libraries: NumPy, Matplotlib, Pandas, SciPy, Keras, Py Torch, TensorFlow Container: Docker Database need: MongoDB
Interfaces	User Interface: Yes, REACT Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MongoDB
Requires	Other AIDEAS Solutions: trigger of an anomaly in the machine behaviour from the AI-AD solution.

Solution architecture

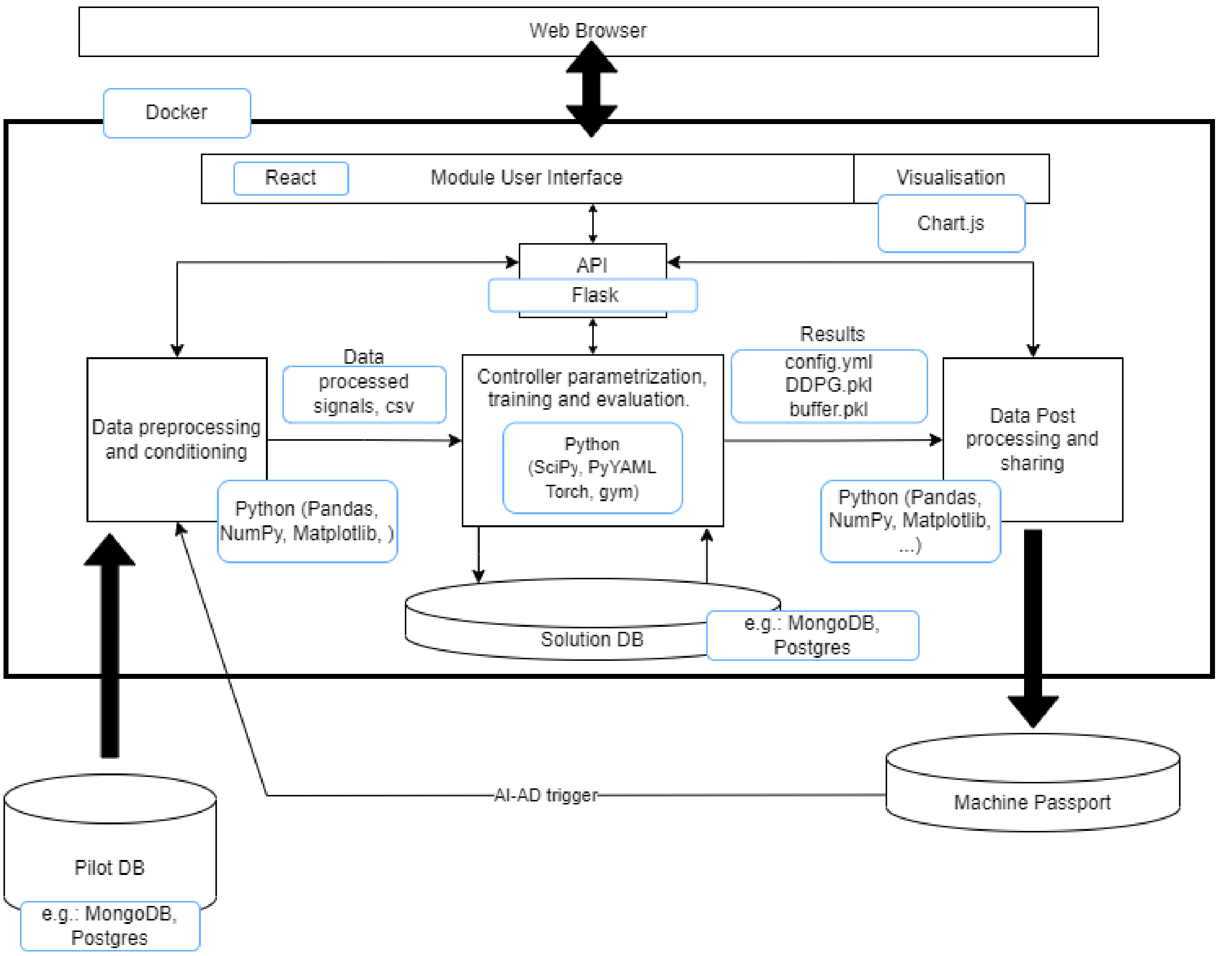


Figure 73. AC implementation architecture.

Details about architecture
AI-AC's backend will be developed in Python using the most common libraries used in data science and machine learning, such as NumPy for array and matrix processing, Pandas for data analysis and processing and SciPy, PyYAML, Py Torch and TensorFlow for training and evaluating machine learning models and Reinforcement Learning algorithms. **AI-AC**s frontend will be developed in REACT, which is a JavaScript library, Redux will be used to manage the application state. Both backend and frontend, will be communicated over a RESTful API using HTTPS protocols. The API could be tested using tools such as Postman. Docker, which is a platform to build, deploy, run and manage containers, will be used to package everything the software needs to run.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/AC.html

5.5.11 QA (Quality Assurance)

Usage Viewpoint
Description – AI-QA-2D
Training: User defines the process (machine and material characteristics) and uploads a set of defect-free samples. The AI-QA-2D method is trained on the samples. Additionally, the user

uploads samples with labelled defects to support training under mixed supervision and to enable evaluation of the performance. This can be performed by the operator or supervisor.

Environment configuration: The operator configures the application with machine and material characteristics. Additional metadata can also be provided.

Deployment: AI-QA-2D solution is deployed and applied to input 2D imagery data to perform a visual inspection (QA). The operator inspects the results (correct detection of presence/absence of visual defects, as well as localization accuracy), The operator can modify the results and as such provide feedback to the AI-QA-2D module to facilitate the feedback loop (optional).

Use Model – AI-QA-2D

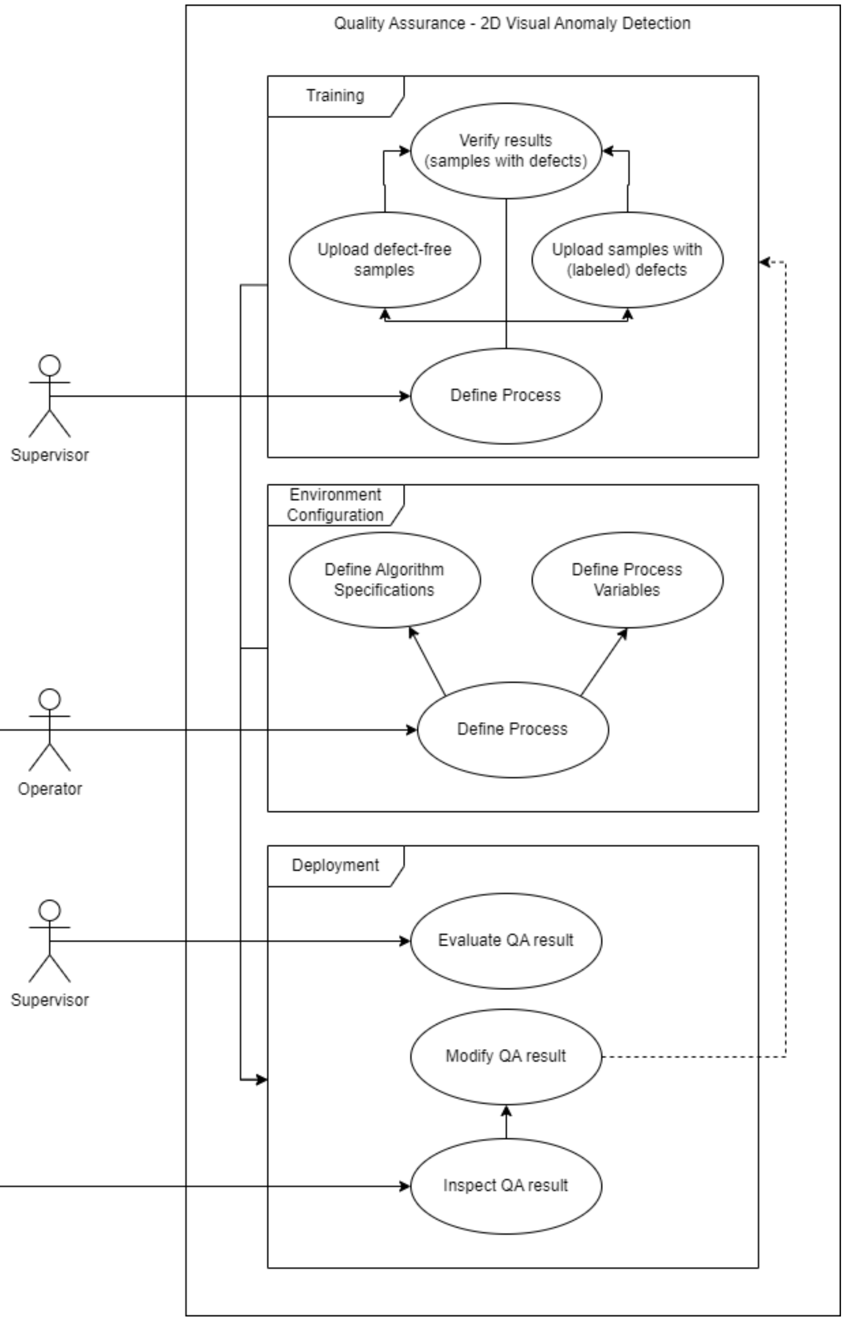


Figure 74. QA - 2D Use Model.

Description – AI-QA-3D
Training: The user defines the process (machine and material characteristics) and uploads a set of objects labelled captures. The AI-QA-3D method is trained on the samples. This can be performed by the operator or supervisor. **Environment configuration**: The operator configures the application with machine characteristics. Additional metadata can also be provided. **Deployment**: AI-QA-3D solution is deployed and applied to input 3D imagery data to perform a visual inspection (QA). The operator inspects the results (correct classification of incoming objects), the operator can modify the results and as such provide feedback to the AI-QA-3D module to facilitate the feedback loop (optional).

Use Model – AI-QA-3D

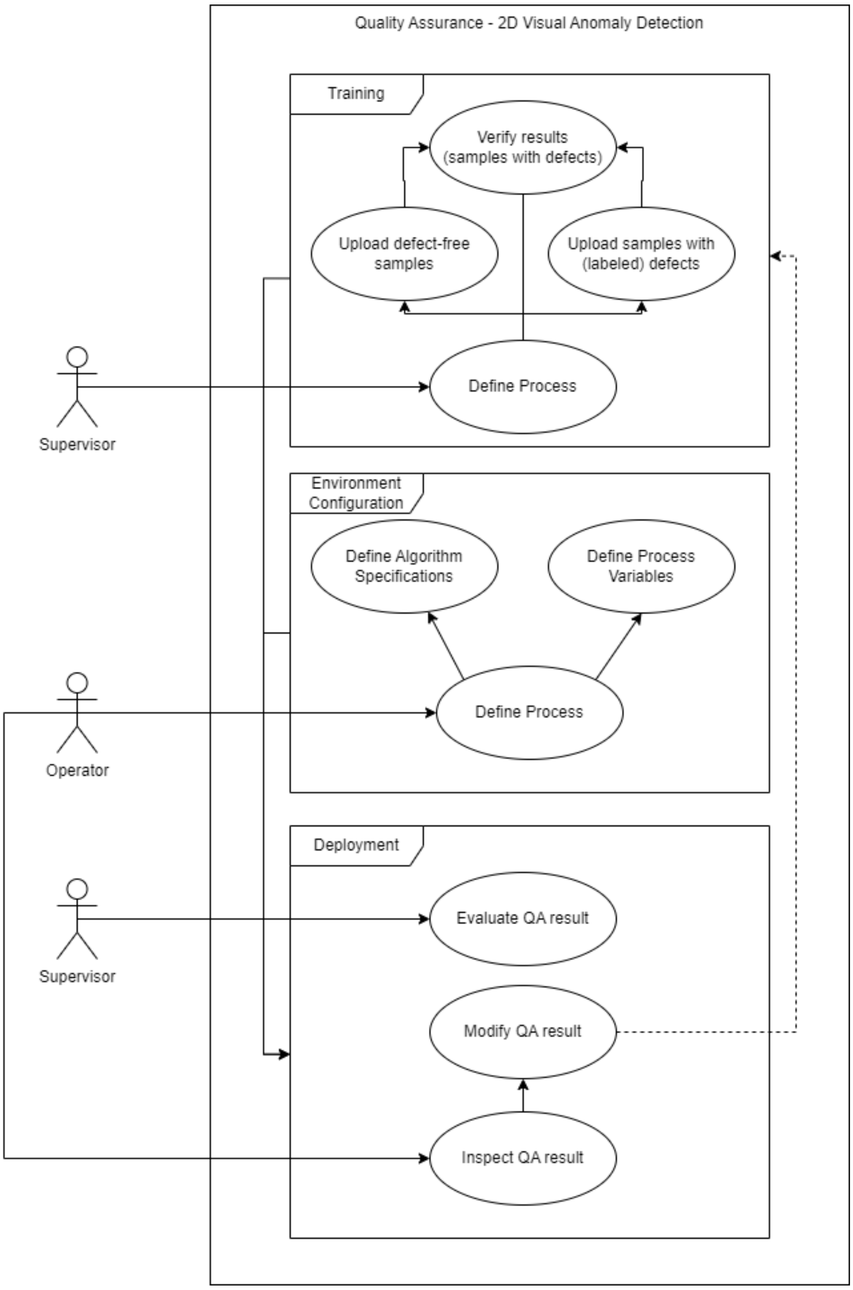


Figure 75. QA - 3D Use Model

Functional viewpoint	
Description – AI-QA-2D	
What	The main functionality of this component is to detect visual defects in 2D imagery input of the product that the machine is producing or represents and input to the machine.
Who	Machine operator, QA supervisor
Where	The solution is deployed in both **edge and enterprise tiers**, operating on the machine itself. It is deployed in the cloud and integrated with the machine's existing interfaces using provided APIs. This combination of edge and enterprise functionality enables AI-assisted QA monitoring of input materials or produced products. Data is not directly captured, but processed 2D imagery is analyzed, defects are detected, and reports are generated. Integration with the machine (scanner) for AI-QA-2D is through cloud-based APIs, which the pilot handles. The solution can also be integrated into their software (SW) instead of the machine. Overall, the focus is more on the enterprise aspect than the edge for both AI-QA-2D and AI-QA-3D.
Why	The main objective is to detect visual defects (2D) in the input or produced material to reduce waste and improve the utilization of the material.

Functional diagram AI-QA-2D

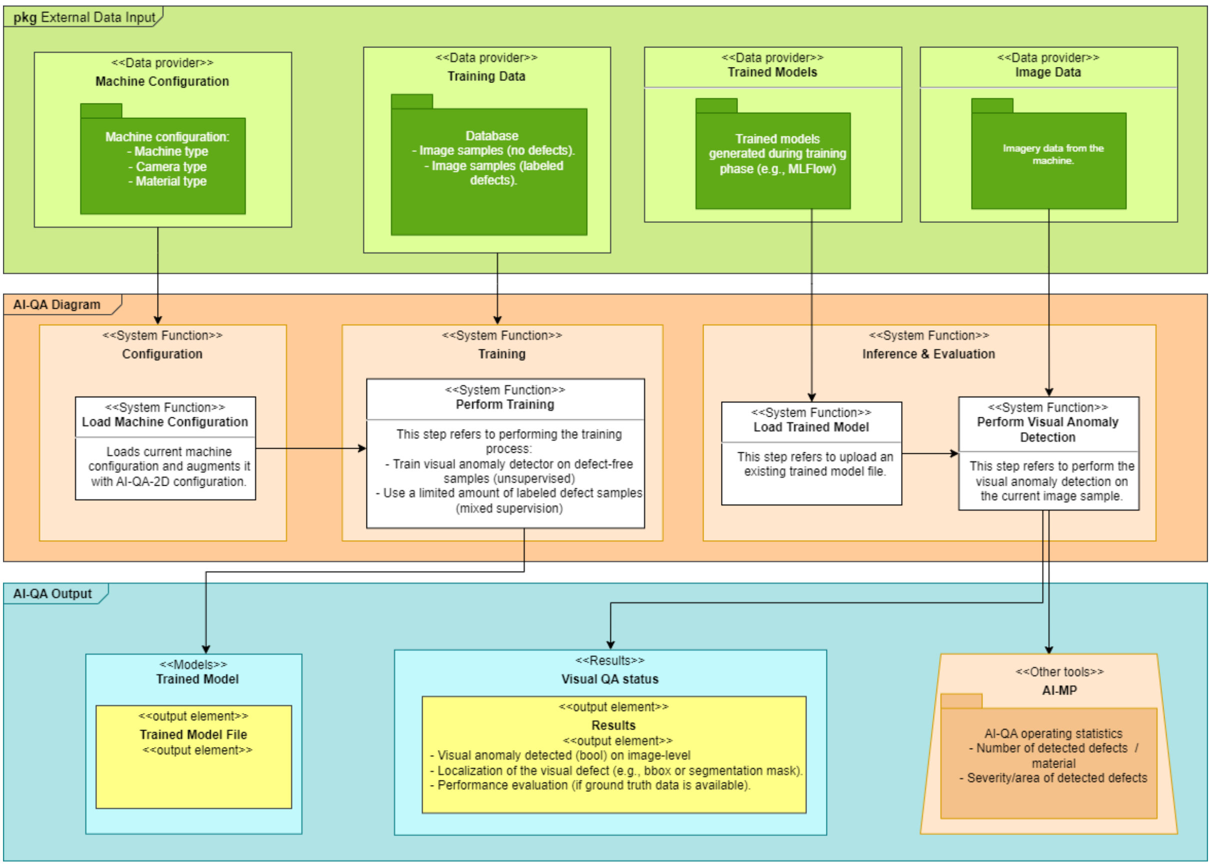


Figure 76. QA - 2D functional diagram.

Description – AI-QA-3D	
What	The main functionality of this component is to classify incoming objects in 3D imagery input of the product that the machine is producing or represents and input to the machine.

Who	Machine operator, QA supervisor.
Where	The solution is deployed in both **edge and enterprise tiers**, operating on the machine itself. It is deployed in the cloud and integrated with the machine's existing interfaces using provided APIs. This combination of edge and enterprise functionality enables AI-assisted QA monitoring of input materials or produced products.
Why	The main objective is to classify objects (3D) in the input or produced material to improve the accuracy of the main visual inspection system.

Functional diagram AI-QA-3D

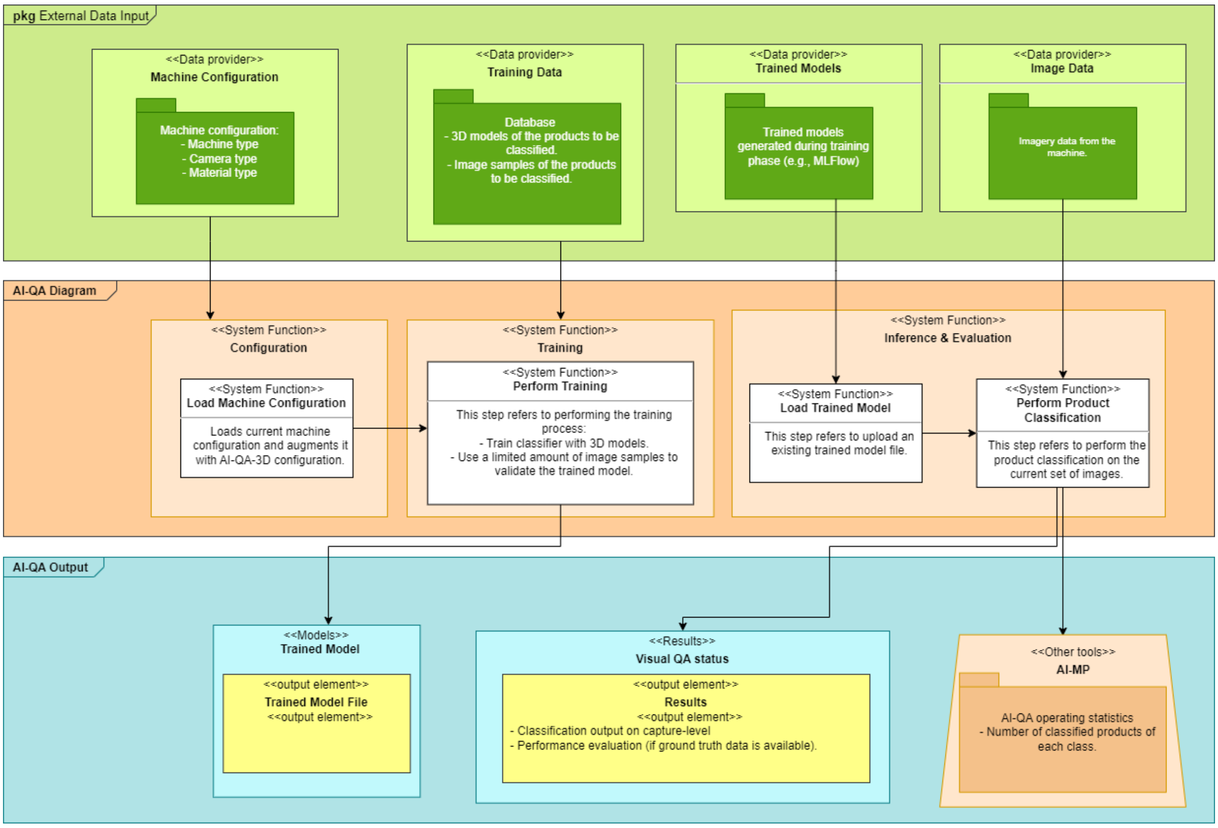


Figure 77. QA – 3D functional diagram.

Implementation Viewpoint

Description of implementation Component

AI-QA-2D is a 2D visual QA inspection submodule of AI-QA.

Technical Description of its Components

Dependencies	Development Language: - Python Libraries: PyTorch Container: Docker, Nvidia-Docker Database need: MLFlow/Databricks will be used for model and experiment versioning. Cloud-based object storage will be used for storing unstructured imagery data. MongoDB might be used for the storage of metadata.

Interfaces	User Interface: No user interface is envisioned, only APIs for the integration to the existing end-user machine and applications. Demo user interfaces will be created using Streamlit and/or Gradio. Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MLFlow/Databricks will be used for model and experiment versioning. Cloud-based object storage will be used for storing unstructured imagery data. MongoDB might be used for the storage of metadata.
Requires	Other N/A Solutions: N/A

Solution architecture

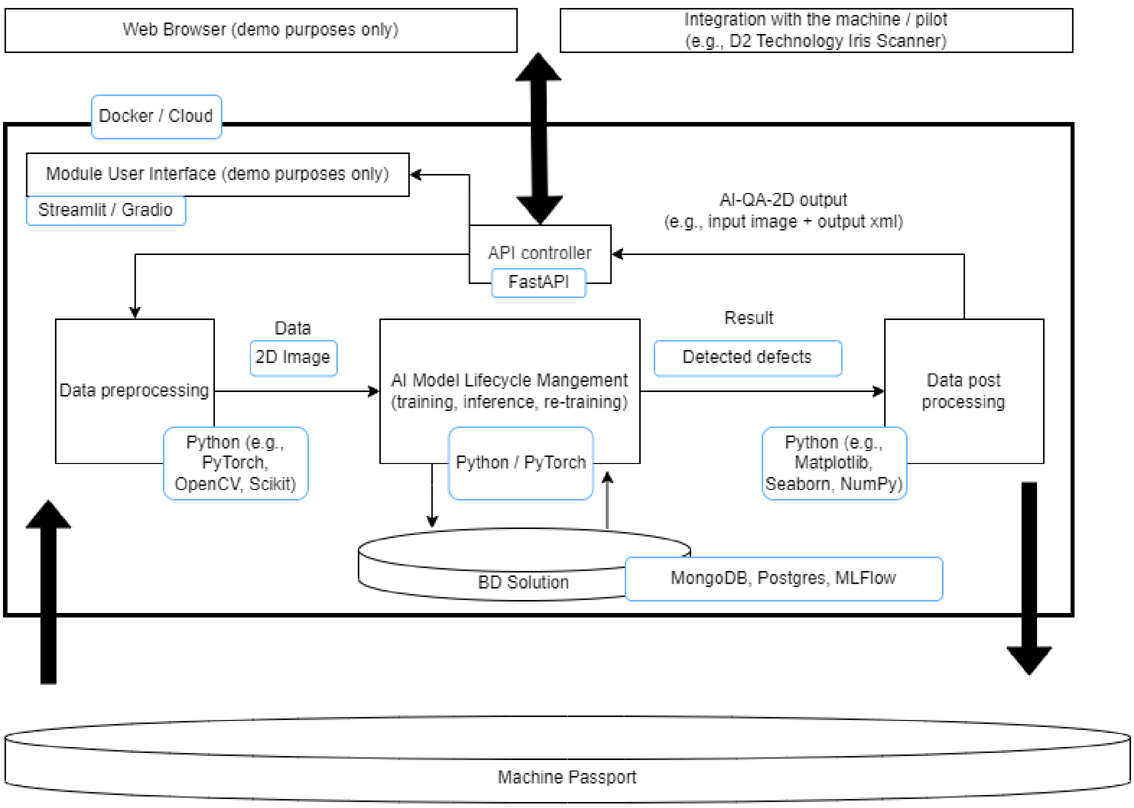


Figure 78. QA – 2D implementation architecture.

Details about architecture

AI-QA-2D solution provides a cloud-based computer-vision-based AI solution for the detection and localization of visual defects in 2D imagery data. The AI solution will be developed in PyTorch1 and provided as a service for further integration into existing pilot machines and/or existing software for the processing and management of images. The service will be deployed in a Dockerized fashion and will support GPU (default), as well as CPU-based execution. The application's AI lifecycle (e.g., experiment and model versioning) will be managed using MLFlow2 (e.g., cloud-managed Databrick's MLFlow). Data will be primarily stored on the user premises (existing databases). The application will additionally support the storage of imagery data in a cloud-based object storage/Datalakes3. The associated metadata will be stored primarily in NoSQL databases (e.g., MongoDB). Microsoft Azure Cloud will be used for the deployment of the solution. We don't envision specific development of user interfaces, as the main purpose of the solution is the integration into existing applications - either on the machine itself, or other applications that are currently used to process imagery data on the pilot side. Nevertheless, we plan to provide demo user interfaces based on Streamlit4 or Gradio5 to enable pilot-independent demonstration of the solution.

Implementation Viewpoint	
Description of implementation Component	
AI-QA-3D is a 3D visual QA inspection submodule of AI-QA.	
Technical Description of its Components	
Dependencies	Development Language: - C Libraries: OpenCV, Tensorflow Container: Docker Database need: SQLite
Interfaces	User Interface: No user interface is envisioned, only APIs for the integration to the existing end-user machine and applications. Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: SQLite
Requires	Other N/A Solutions: N/A
Solution architecture	

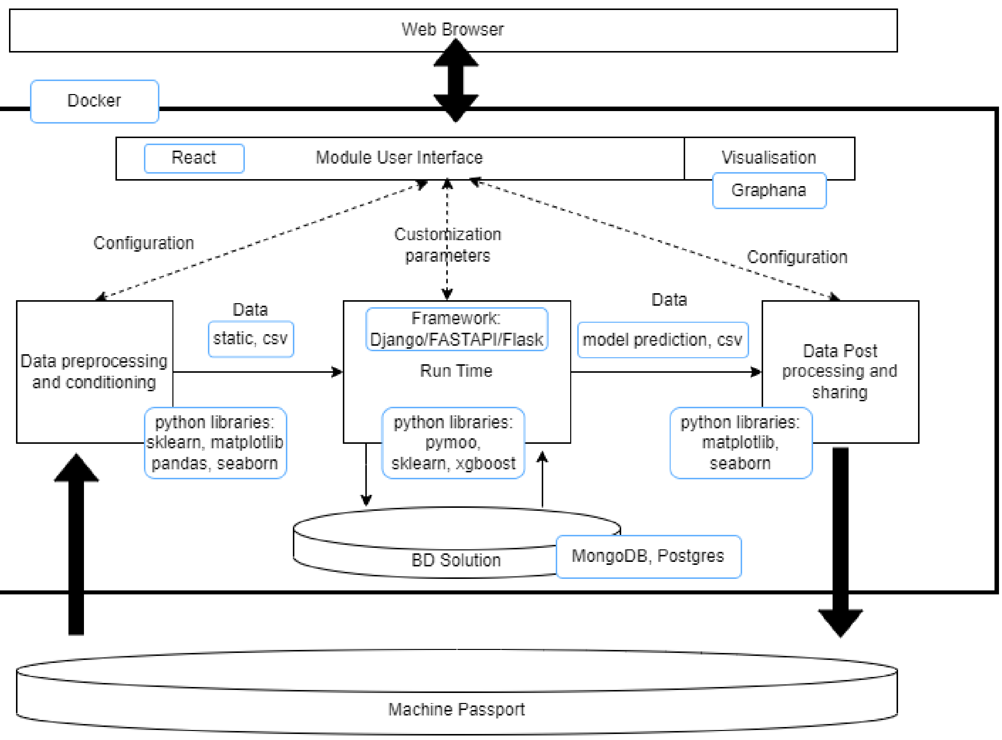


Figure 79. QA - 3D implementation architecture.

Details about architecture

AI-QA-3D solution provides a computer-vision-based AI solution for the classification of incoming objects with 3D capture data. The AI solution will be developed in C and presented as a Python-developed service for further integration into existing pilot machines and/or existing software for the processing of incoming objects. The service will be deployed in a Dockerized fashion. Data will be mainly stored on the user premises. We don't envision specific development of user interfaces, as the main purpose of the solution is the integration into existing applications. Nevertheless, we plan to provide demo user interfaces based on Streamlit1 to enable pilot-independent demonstration of the solution.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/QA.html

5.5.12 PM (Prescriptive Maintenance)

Usage Viewpoint
Description
An initial step of configuration is necessary to define the scope where the Prescriptive Maintenance will be deployed, the machine to be studied. For this task an engineer is required, so the machine is defined properly, these are the required tasks: First, the different machine components will be defined, that is, the different relevant zones of study in which the machine can be divided. Then, the different process variables present, such as temperatures, currents, pressures, speeds. And finally, the association between process variables and components, meaning, which variables affect directly which component. As an additional step, it may be necessary to define working conditions such as which tool is currently being used, the different processes performed or define the conditions that indicate that the machine is not idle or working. Once the machine definition is completed, a model of the machine will be trained, for this task the supervisor and the operator must work together. The supervisor will define the normal and limits of working conditions for each process variable of the study, that is, defining the thresholds in which the machine has a proper behaviour and those thresholds in which the machine or some of its parts may break down. To train the model a dataset is needed, obtained from a file or from a DB; the desired algorithm and its parameters must be defined and, also, the RUL hypothesis for each process variable. Finally, the training process can be performed. As the last step, the evaluation process will be performed by the operator. This process is a continuous task, where RUL will be obtained for the whole machine and the desired specific components. The solution will give an insight into the RUL. Every task performed by the operator can be performed by the supervisor and so on for the higher hierarchy users.

Use Model

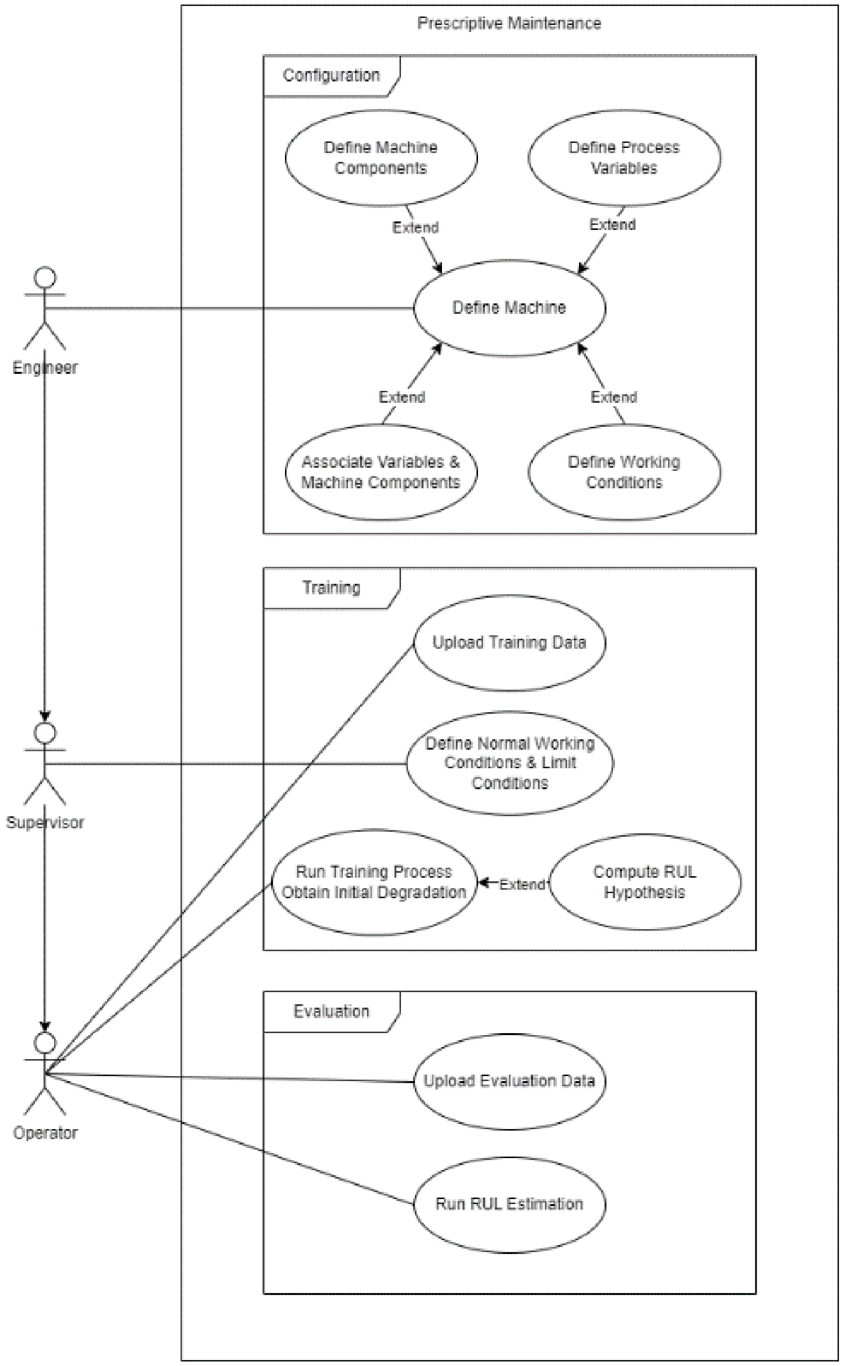


Figure 80. PM Use Model.

Functional viewpoint	
Description	
What	The main feature of this component is to get an estimation of the remaining useful life of the machine, in which is deployed, or in any of its components. This RUL estimation could be computed in pseudo real-time.
Who	Process Engineer, Maintenance Manage, Operator.
Where	Platform Tier.
Why	To obtain RUL estimation of the machine or any of its components.

Functional diagram

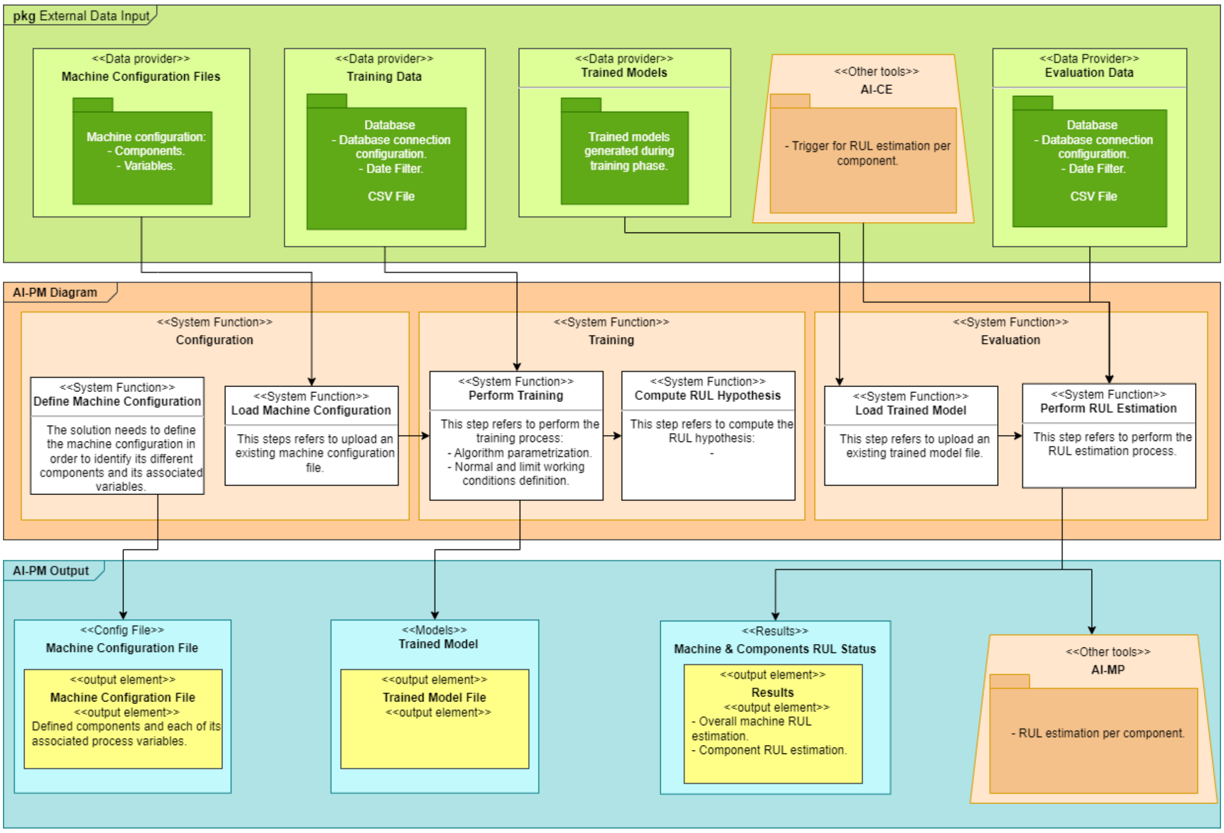


Figure 81. PM functional diagram.

Implementation Viewpoint

Description of implementation Component

AI-PM is a toolkit for anomaly detection at both machine and component levels.

Technical Description of its Components

Dependencies	Development Language: - Python Libraries: NumPy, Pandas, SciPy, Keras, Py Torch, TensorFlow Container: Docker Database need: MongoDB
Interfaces	User Interface: Yes, REACT Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MongoDB
Requires	Other AIDEAS Solutions: AI-CE (used as a trigger to know when abnormal behaviour starts)

Solution architecture

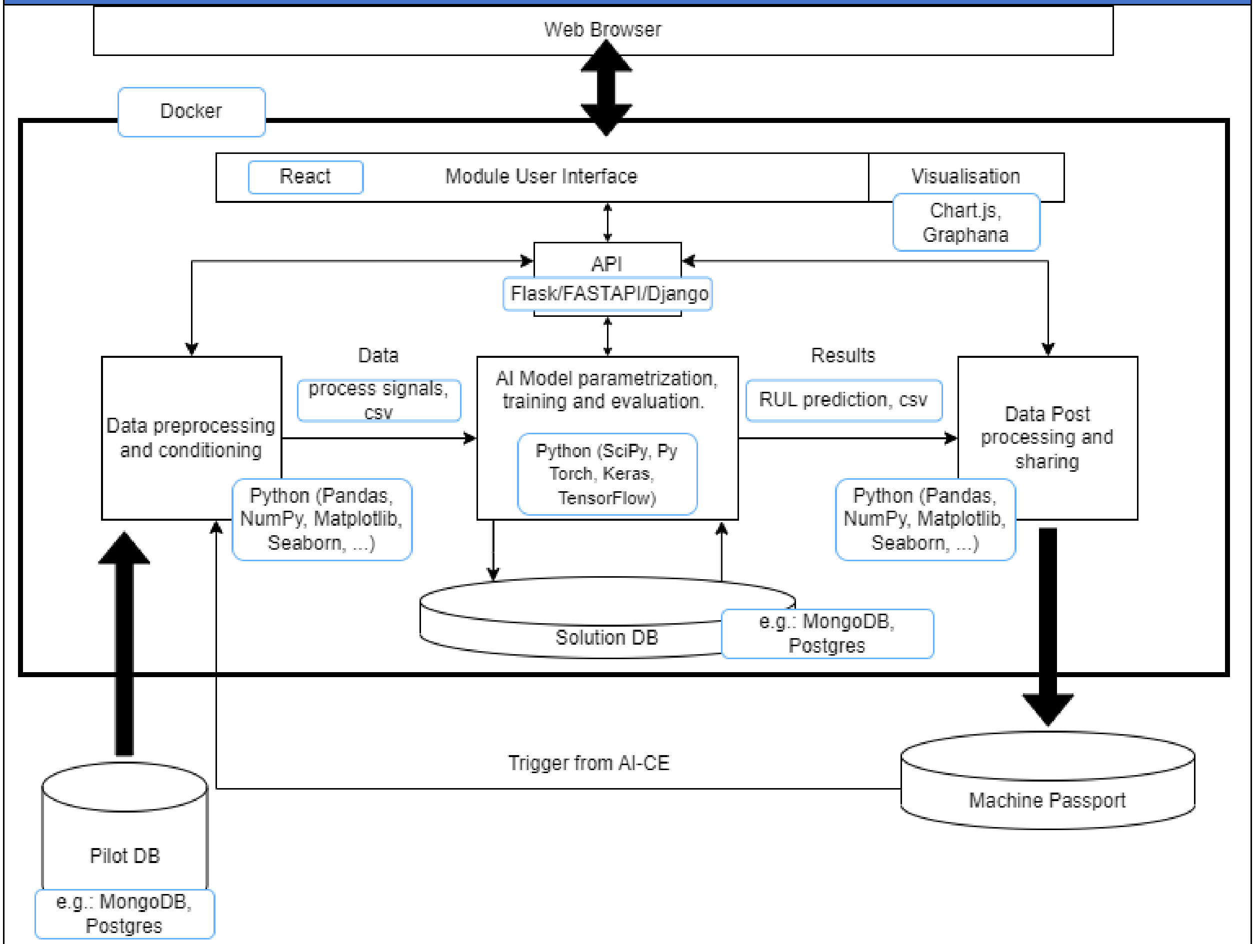


Figure 82. PM implementation architecture.

Details about architecture
AI-PM's backend will be developed in Python using the most common libraries used in data science and machine learning, such as NumPy for array and matrix processing, Pandas for data analysis and processing and SciPy, Keras, Py Torch and TensorFlow for training and evaluating machine learning models. **AI-PM**'s frontend will be developed in REACT, which is a JavaScript library, Redux will be used to manage the application state. Both backend and frontend, will be communicated over a RESTful API using HTTPS protocols. The API could be tested using tools such as Postman. Docker, which is a platform to build, deploy, run and manage containers, will be used to package everything the software needs to run.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/PM.html

5.5.13 SR (Smart Retrofitter)

Usage Viewpoint
Description
The SR solution involves the realisation of a hardware part relating to the box and a software part enabling the monitoring and control of the behaviour of the consumption parameters of interest. As illustrated in the figure, the software part includes a user identification system. Identification is by facial recognition or login ID. Data access permissions can only be granted by the

administrator. All other functions can instead be managed and controlled by the administrator and the user (previously logged in). Once logged in, it is possible to view data in real-time, view the data history and check that the measured variables are within the 'normal behaviour' of the system. In fact, an algorithm based on historical data is implemented for the control, which estimates the behaviour and verifies its conformity within the threshold limits. An alert message is sent and displayed on the HMI if the parameters do not meet the set limits.
Use Model

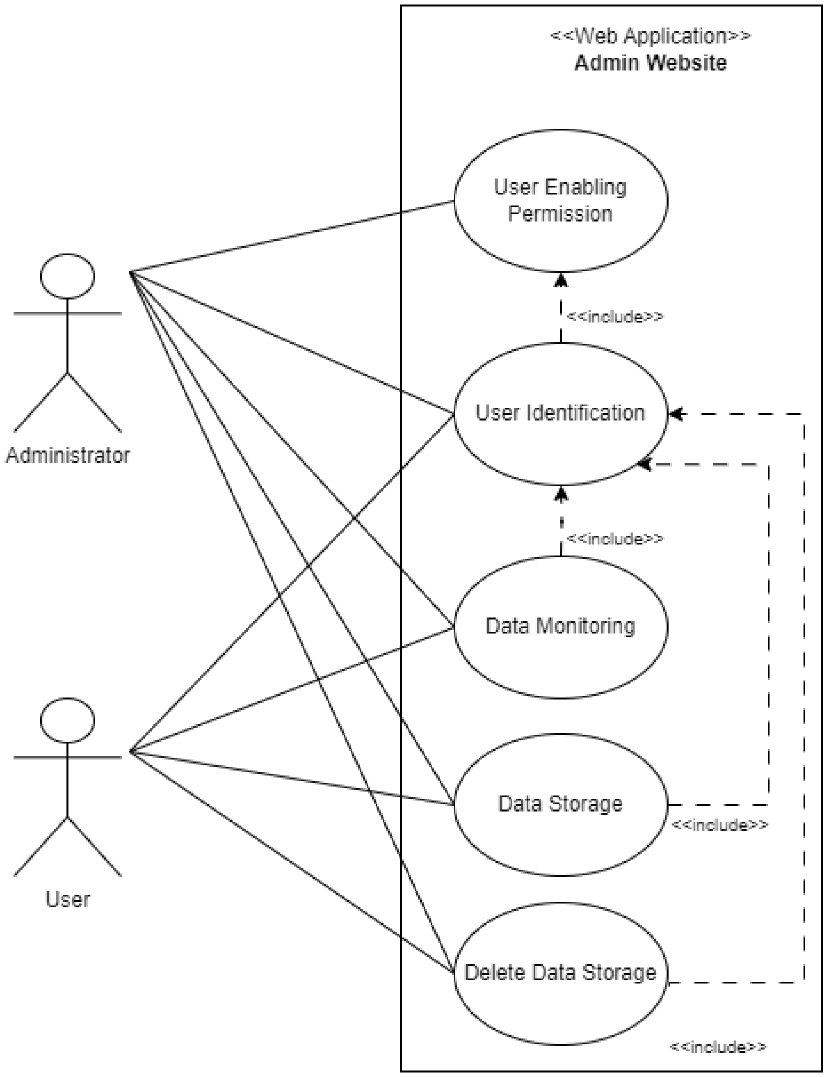


Figure 83. SR Use Model.

Functional viewpoint	
Description	
What	The main feature of this component is to monitor and control the behaviour of 4 parameters of interest. In addition, there is a section where you can view the stored data of the variables of interest.
Who	Production managers, Maintenance operators
Where	Edge Tier

Why	Unlike the new machines produced by D2T, the old machines do not have a system for monitoring and controlling certain parameters of interest or the associated connection to a centralised data collection system.

Functional diagram

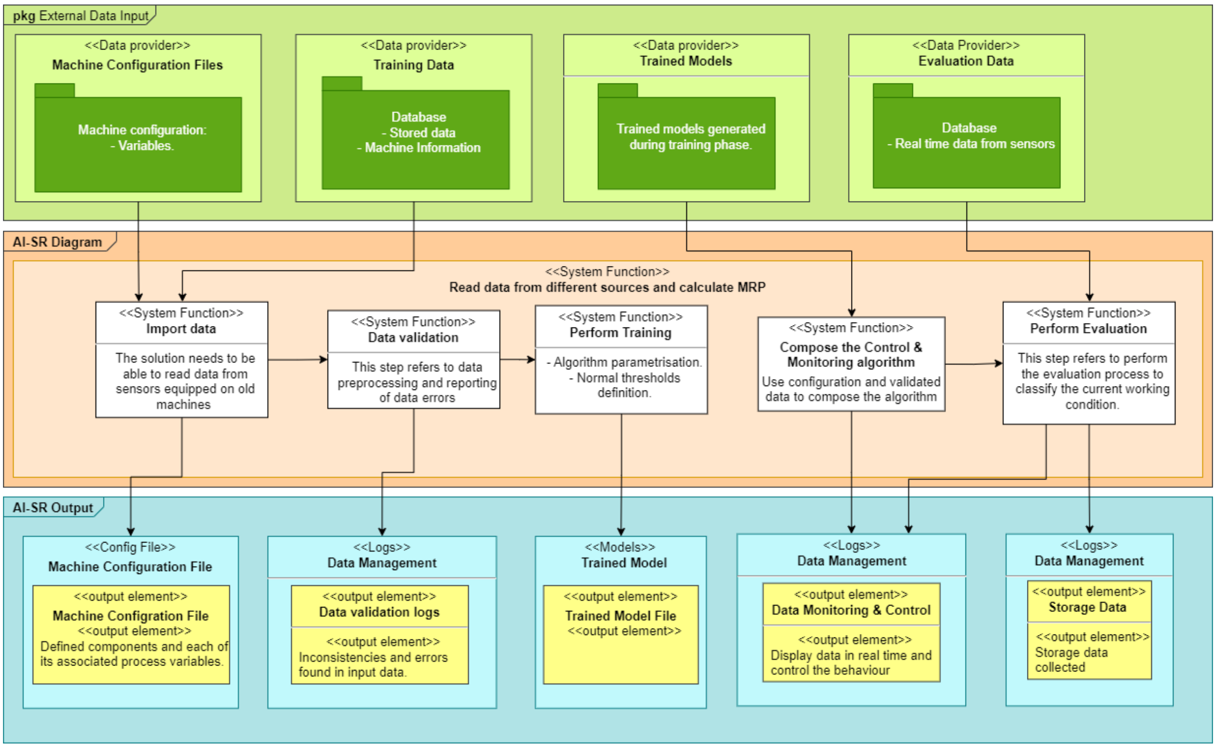


Figure 84. SR functional diagram.

Implementation Viewpoint

Description of implementation Component

AI-SR is for bringing innovation to an old machine.

Technical Description of its Components

Dependencies	Development Language: - Python Libraries: Keras, sklearn, Numpy, Matplotlib, Pandas Container: Docker Database need: MySQL
Interfaces	User Interface: Wordpress Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MySQL
Requires	Other N/A Solutions: N/A

Solution architecture

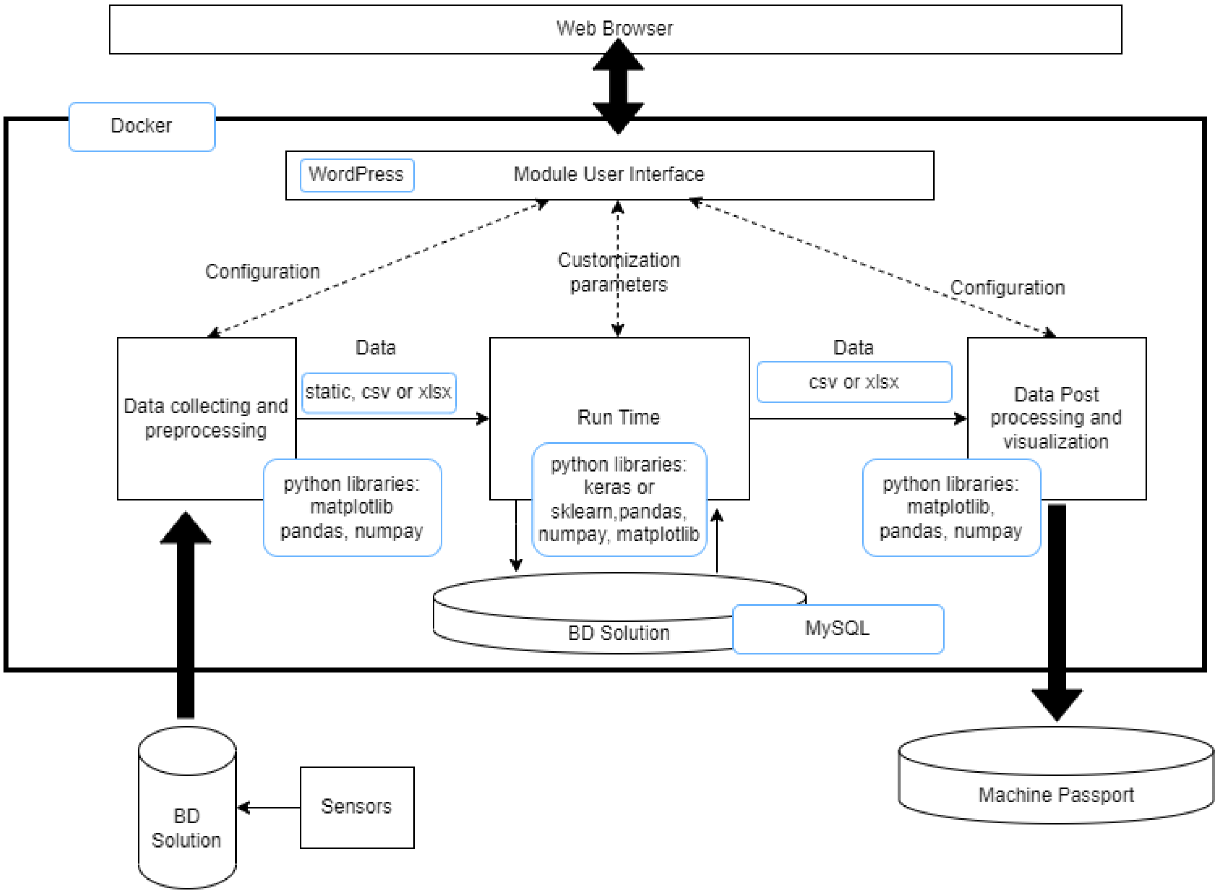


Figure 85. SR implementation architecture.

Details about architecture
The Python programming language will be used to create the **AI-SR** tool, with the use of libraries that are well-known and popular in the data science community. These libraries include NumPy for fast processing of arrays and matrices, Pandas for in-depth data analysis and Keras/sklearn for neural networks and machine learning algorithms. Data visualisation will be realised with the Matplotlib tool. WordPress software will be used for the front-end development of the AI-SR solution. A RESTful API will enable communication between the back-end and front-end using HTTPS protocols to secure data transmission. A MySQL database will host the actual data. To speed up the deployment process and ensure the portability of the software, Docker will be used. This platform allows all the necessary components and dependencies to be grouped to ensure efficient software execution.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/SR.html

5.5.14 LC (LCC/LCA/S-LCA)

Usage Viewpoint
Description
The AI-LC solution represents a disassembly support tool within the business context. The proposed system sees an AI algorithm assisting operators during the disassembly phase. The data that the algorithm takes as input are the outputs of the various Life Cycle Assessment (LCA), Life Cycle Costing (LCC), Social Life Cycle Assessment (S-LCA) analyses and the product's bill of materials (BOM). Before processing begins, the disassembly process operator performs the various

analyses and uploads them into the system. After logging into the AI-LC system with his personal account (the administrator provides credentials and an account to each operator), the operator waits for the algorithm to perform the analysis. The algorithm will return as output the optimal sequence for proper disassembly of all product components.
Use Model

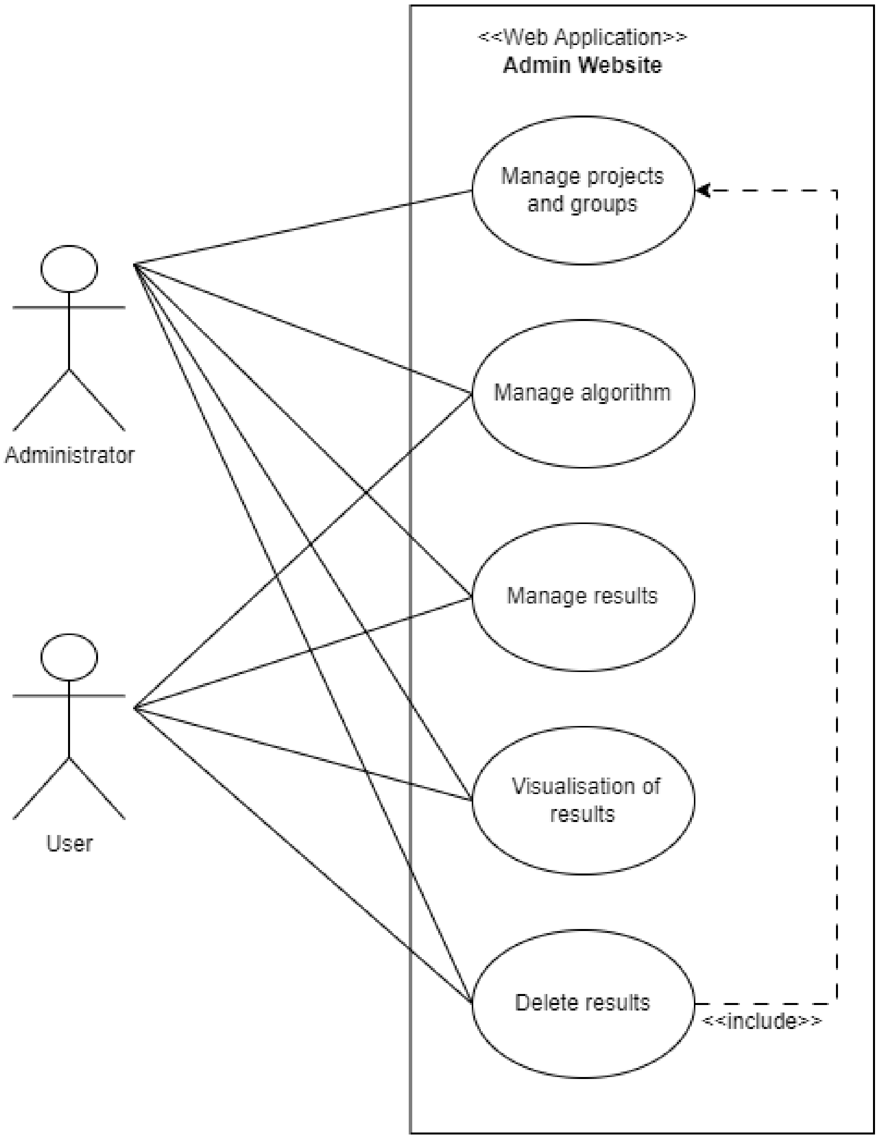


Figure 86. LC Use Model.

Functional viewpoint	
Description	
What	The main feature of this component is to identify the best disassembly choice considering several parameters such as LCA, LCC, and SLCA analyses previously performed on the assembly.
Who	Production managers, Maintenance operators
Where	Platform layer
Why	The purpose of this component is to support the operator who disassembles the product. In fact, this algorithm will help him to be more productive by supporting him in choosing the end-of-life of the product.

Functional diagram

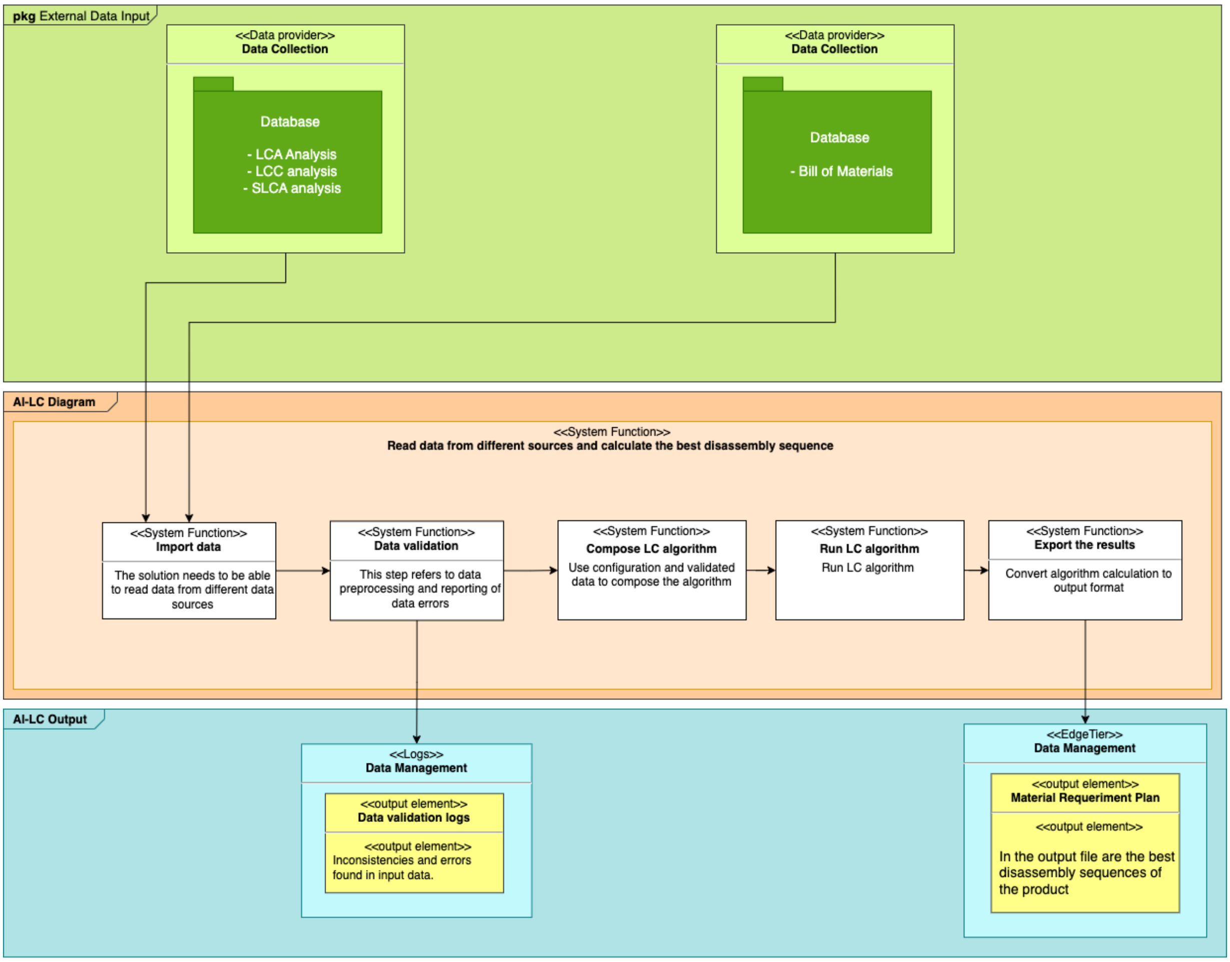


Figure 87. LC functional diagram.

Implementation Viewpoint	
Description of implementation Component	
AI-LC is a tool in support of sustainable disassembly.	
Technical Description of its Components	
Dependencies	Development Language: - Python Libraries: Pandas, Networkx, Numpy, Matplotlib, Json Container: Docker Database need: MySQL
Interfaces	User Interface: WordPress Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MySQL
Requires	Other N/A Solutions: N/A

Solution architecture

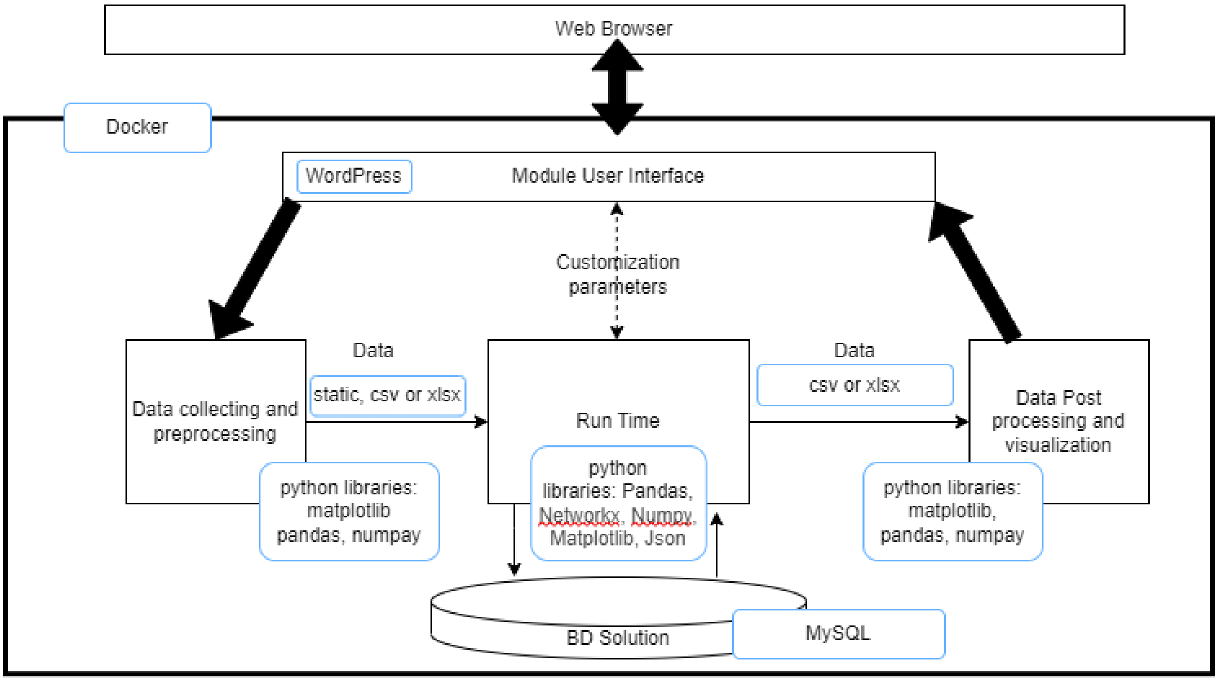
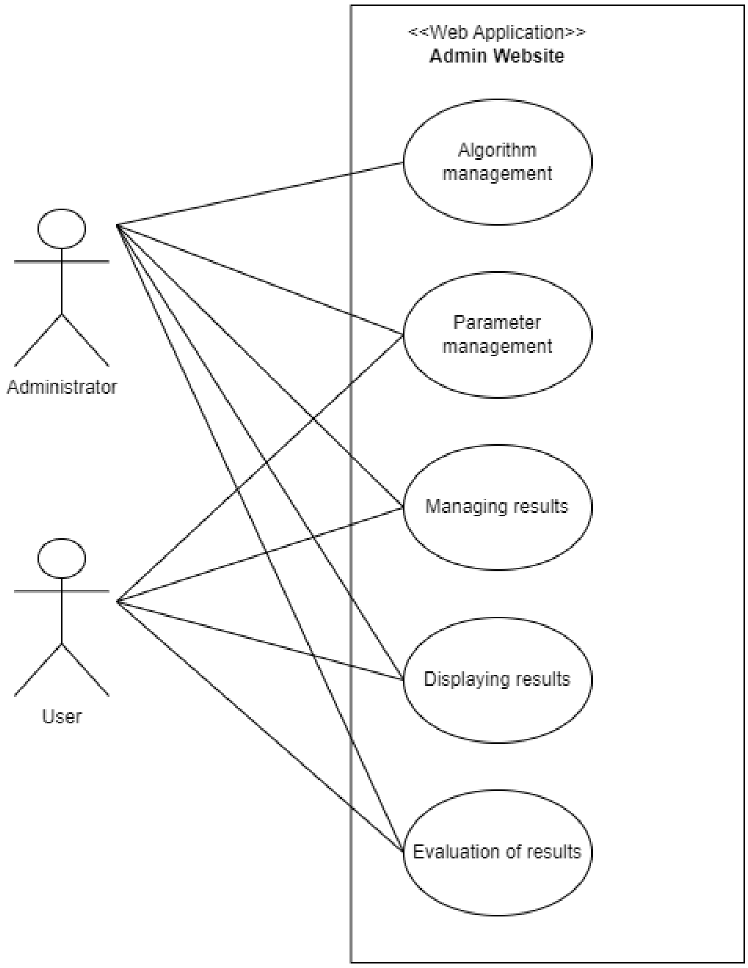


Figure 88. LC implementation architecture.

Details about architecture
The AI-LC tool will be developed using the Python programming language, leveraging popular libraries commonly used in the field of data science. These libraries encompass NumPy for efficient processing of arrays and matrices, Pandas for comprehensive data analysis, and Networkx for manipulating data through graphical techniques. Lastly, the Matplotlib library will be employed for data visualization. For the frontend development of AI-LC, the WordPress software will be utilized. Communication between the backend and frontend will be facilitated by means of a RESTful API, employing HTTPS protocols to ensure the secure transmission of data. The data itself will be stored in a MySQL database. To guarantee the portability of software and streamline the deployment process, Docker will be employed. Docker is a platform that allows for the bundling of all the necessary dependencies and components required to ensure the smooth operation of the software.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/LC.html

5.5.15 DIS (Disassembler)

Usage Viewpoint
Description
The AI-DIS solution represents a disassembly support tool within the industrial context. The proposed system is equipped with both industrial cameras that can analyze the current state of different cutting tools and an AI algorithm that can identify the possible end of life of the analyzed tool.

Before starting the processing, the operator in charge of the turning process checks the status of the machine and cutting tools. After logging into the AI-DIS system with his or her personal account (the administrator provides credentials and an account to each operator), the operator can start performing the analysis on the tool. The AI algorithm in the system is already trained to recognize different types of objects. Should it be necessary to add a new category of cutting tools to be recognized, only the administrator is able to access the algorithm and train it again. The AI-DIS system can track the history of the analyses performed. All analyses are recorded within a database that can be accessed by both the user and the administrator.
Use Model
 **Figure 89.** DIS Use Model.
Functional viewpoint
Description

What	The main feature of this component is to check the condition of cutting tools with the aim of finding out whether they are still usable or need to be disposed of.
Who	Production managers. Maintenance operators
Where	Edge tier
Why	Several industrial processes are needed to produce well-made machines; if even one of them is poor, it would result in a poor result. This component is used to identify the state of the cutting tools with

	the purpose of ensuring the quality required to complete the process of turning.

Functional diagram

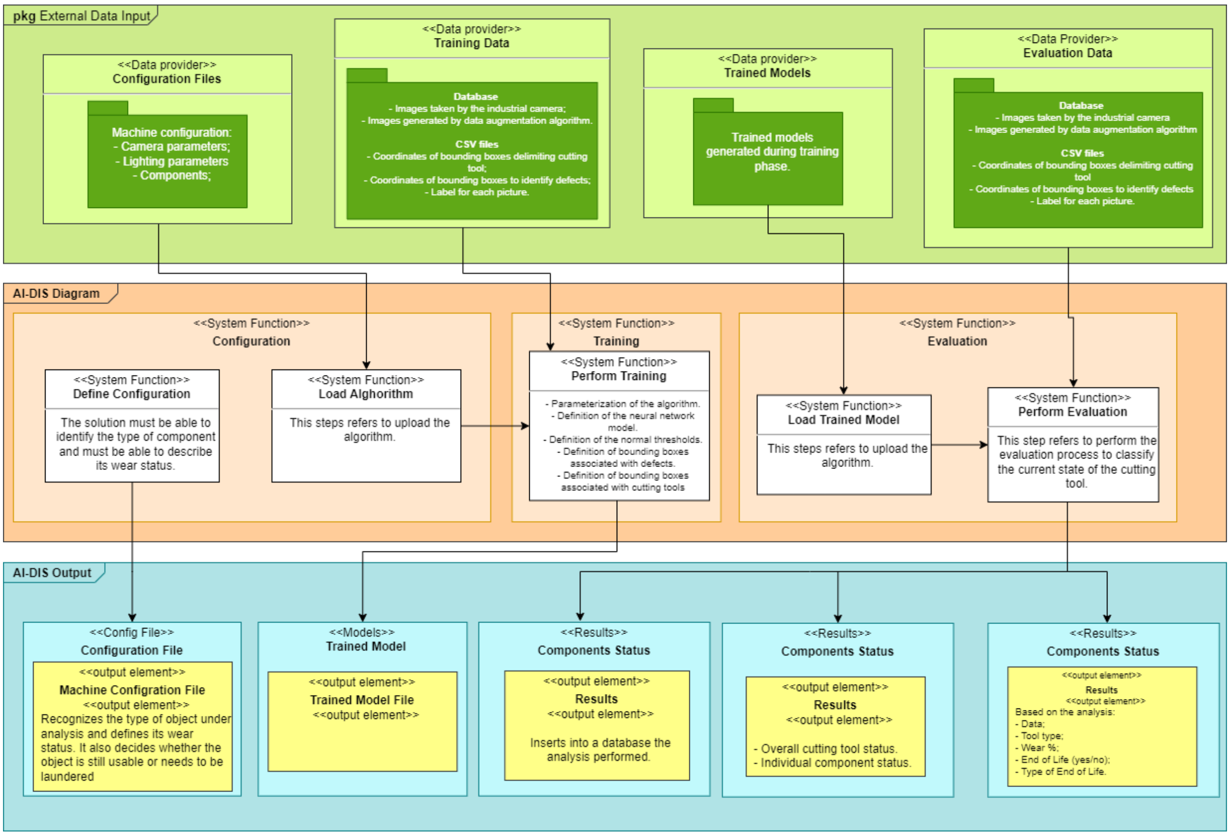


Figure 90. DIS functional diagram.

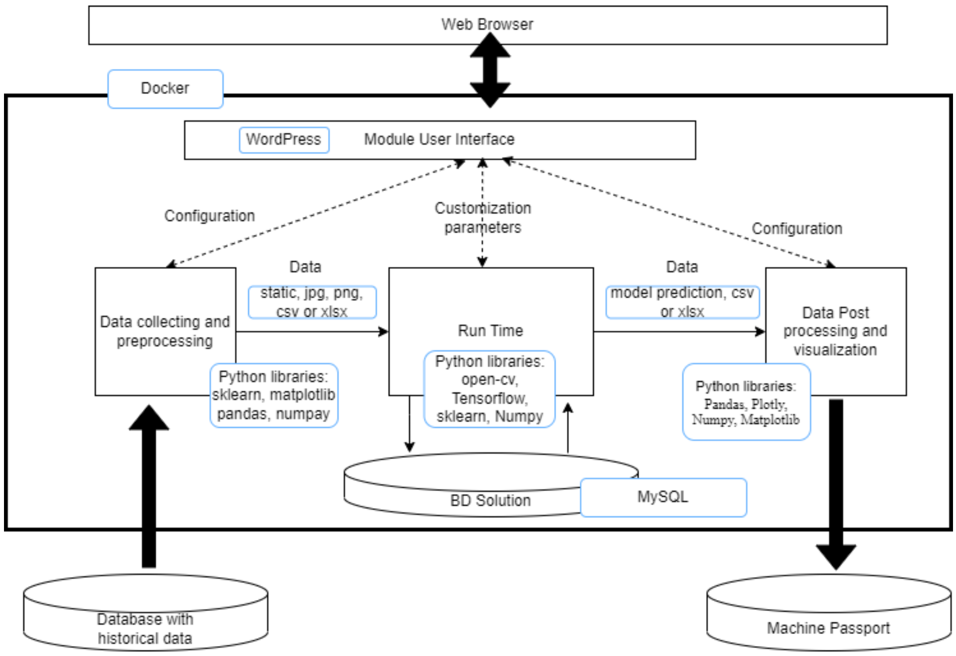
Implementation Viewpoint

Description of implementation Component

AI-DIS is a tool in support of quality management of products being disassembled.

Technical Description of its Components

Dependencies	Development Language: - Python Libraries: Keras, sklearn, Numpy, Matplotlib, Pandas, Tensorflow, Plotly, OpenCv Container: Docker Database need: MySQL
Interfaces	User Interface: WordPress Synchronous/Asynchronous Interface: RESTful APIs Network/Protocols: HTTP/HTTPS Data Repository: MySQL
Requires	Other N/A Solutions: N/A

Solution architecture
 **Figure 91.** DIS implementation architecture.
Details about architecture
The AI-DIS tool will be created using the Python programming language, utilizing popular libraries commonly employed in data science and machine learning. These libraries include NumPy for efficient array and matrix processing, Pandas for comprehensive data analysis and manipulation, as well as SciPy, Keras, and TensorFlow for training and evaluating machine learning models. The OpenCv library is used to manipulate the images taken by the industrial camera, both the Matplotlib and Plotly libraries are used for graphical representation. WordPress software will be utilized for the frontend development of AI-DIS. Communication between the backend and frontend will be facilitated through a RESTful API, utilizing HTTPS protocols for secure data transmission. The data will be stored within a MySQL database. To ensure the software's portability and ease of deployment, Docker will be employed. Docker is a platform that enables the packaging of all the necessary dependencies and components required for the software to run smoothly.
More information here: https://viewpoints.aideas-srv.cigip.upv.es/DIS.html

5.6 Edge/Fog/Cloud Domain

In a reference architecture, the EDGE, Fog and Cloud domains refer to different layers or tiers in the distributed computing infrastructure. Each of these domains plays a specific role in data management and processing, providing different levels of computing and storage capacity.

- The **EDGE domain** is at the layer closest to the end devices or sensors. It refers to the computational and storage resources that are located at the edge of the network, close to where the data is generated. These resources are characterised by their limited capacity and physical proximity to devices and sensors. The EDGE domain enables real-time data processing and analysis, which is crucial for applications that require low latency and fast response. In addition, it also helps to reduce the load on the network by performing preliminary processing of the data before sending it to higher domains, such as Fog or Cloud.

- The **Fog domain** sits between the EDGE domain and the Cloud domain. It refers to an intermediate layer that provides geographically distributed computing and storage resources closer to the devices than the Cloud domain. In this layer, more advanced and complex processing of the data generated in the EDGE takes place. The Fog infrastructure leverages servers and edge devices (such as routers and switches) to provide additional storage and computing capabilities. This enables more sophisticated data analytics and delivers services closer to the data's point of origin, further reducing latency and improving network efficiency.
- The **Cloud domain** is the top layer of the architecture and represents the large-scale computing infrastructure in remote data centres. This is where the most powerful and scalable compute and storage resources are located. The Cloud domain enables massive data storage, intensive processing, and large-scale application execution. It offers virtualised computing and storage capabilities that can be accessed remotely over the network. This layer is particularly suitable for applications that require large computational resources, advanced analytics, machine learning and long-term storage.

Considering that AIDEAS solutions are deployed at the application domain level, it is true that they require analysis of the different points within the architecture from which they can obtain data. As a result, we have the following table, which provides a visual mapping.

Input Data	AIMDO	AIMDG	AICAx	AIPO	AIFO	AIDO	AIMC	AICE	AIAD	AIAC	AIQA	AIPM	AISR	AILC	AIDIS
Edge Domain				✓		✓				✓	✓		✓		✓
Fog Domain		✓					✓	✓	✓		✓	✓		✓	
Cloud Domain	✓		✓		✓						✓				

Table 28. Solutions Domains.

5.7 Enterprise Domain

The business domain in a reference architecture refers to the layer that encompasses an organization's internal IT infrastructure and systems. It represents the technology resources and applications that support the internal operations of the organization, including data management, business processes, communication, collaboration, and other business-specific functions.

Within the business domain, various components and systems may be present, such as:

- **Data management systems**: Includes databases, data warehouses and data integration platforms that are used to store, manage, and analyze the organization's data. These systems ensure data integrity, security and accessibility for different business applications and business intelligence tools.
- **Collaboration and communication** tools: These tools facilitate communication and collaboration among the organization's employees. They may include email systems, instant messaging platforms, project management tools, document management systems and virtual

meeting solutions. These tools enable effective teamwork, information sharing and coordination among employees.

- **Security and identity management**: This component encompasses security measures and systems that protect the organization's data, networks and information assets. It includes firewalls, intrusion detection and prevention systems, access control mechanisms and identity management solutions to ensure data privacy and integrity and compliance with regulatory requirements.
- **Business intelligence and analytics**: These are tools and systems that enable data analysis, reporting and business insight. Business intelligence platforms collect and analyze data from a variety of sources to provide meaningful information and metrics to support decision-making processes within the organization.
- **Integration and middleware**: This component includes middleware and integration platforms that enable seamless communication and interoperability between different enterprise systems, applications and data sources. It enables the exchange and integration of data between different systems, improving efficiency and data consistency.

The enterprise domain plays a crucial role in supporting the internal operations and management of an organization. It provides the technology infrastructure, applications and systems needed to facilitate data-driven decision-making, streamline business processes, improve collaboration, and ensure the security and integrity of enterprise data.

6. Conclusions and Next Steps

The analysis conducted from the four key viewpoints (business, usage, functional, and implementation). Each of these points of view is worked on in the following tasks: T2.2 – T2.3 – T2.4 – T2.5. The combination of the outcomes derived from the different viewpoints will be used to develop a comprehensive reference architecture. The results will encompass inputs from the business viewpoint, including business considerations, regulations, and stakeholder perspectives. The usage viewpoint will involve identifying tasks, roles, or activities to be performed within the framework. From the functional viewpoint, the architecture will be decomposed into its Control, Operations, Information, Application, and Business domains. The implementation viewpoint will involve identifying associated flows and conducting an analysis and selection of the technologies necessary for successful implementation.

For the development of the architecture, the contributions of other projects like AIDEAS have been considered with the aim of building the architecture based on the previous experience of other proposals of the same level of complexity. In addition, an investigation of the current reference architectures that adapt to the project has been carried out, with this study it has been decided to base it on the IIRA architecture and to develop the different points of view of each of the solutions.

The definition of the AIDEAS RA is a fundamental step for the success of the project. At the same time, it provides a clear view of the key components, interactions and technology standards required by defining the four points of view (business, usage, functional and implementation).

The reference architecture that has been defined stems from the needs of the project and is therefore a well-founded architecture that supports in its different layers all the necessary components to ensure seamless operability. It also facilitates collaboration between the different teams and stakeholders by establishing a common language and a shared understanding of the project structure.

This provides a first instance of the connections between the solutions, the interfaces and the users. This first version of the architecture fulfils the objectives set for the project, because even if changes are later necessary due to readjustments in the scenarios or technology, what has been done so far brings great value to the project by providing valuable information on which to base the development of the solutions.

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