



AGILEHAND

D3.1 – AGILEHAND Reference Architecture

WP3 – DESIGN: AGILEHAND
Architecture and Integration



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ABSTRACT	<p>The creation of the AGILEHAND framework, which will support the whole life cycle of project equipment, will be the focus of this work package, which is intended to increase the sustainability, agility, and resilience of the business of manufacturing companies.</p> <p>To achieve this target, the AGILEHAND Reference Architecture (RA) will be conceptualized in accordance with the relevant technical standards, beginning with a thorough study and alignment of the most prevalent reference architectures in manufacturing and their respective applications.</p> <p>This work will be done concurrently with those of its views, providing a framework that iteratively addresses any architectural problems that may come up during conception.</p>			

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ABBREVIATIONS/ACRONYMS

AAS	Asset Administration Shell
AI	Artificial Intelligence
BDA	Big Data Analytics
CPS	Cyber-Physical Systems
DSS	Decision Support System
EtherCAT	Ethernet for Control Automation Technology
UI	User Interface
HTTP	Hypertext Transfer Protocol
IIC	Industrial Internet Consortium
IIRA	Industrial Internet Reference Architecture
IIS	Industrial Internet System
IIoT	Industrial Internet of Things
IMSA	Intelligent Manufacturing System Architecture
IoT	Internet of Things
JSON	Javascript Object Notation
MQTT	Message Queuing Telemetry Transport
MTCConnect	Machine Tool Connect
OPC-UA	Open Platform Communications - Unified Architecture
OT	Operational Technology
PLC	Programmable logic controller
SCADA	Supervisory Control And Data Acquisition
SME	Small and Medium Enterprise
RA	Reference Architecture
RAF	Reference Architecture Framework
RAMI4.0	Reference Architectural Model Industry 4.0
REST	Representational State Transfer
Vf-OS	Virtual Factory Operating System
XML	Extensible Markup Language
ZDM	Zero-Defects Manufacturing
ZDMP	Zero Defects Manufacturing Platform

Executive summary

The objective of the **AGILEHAND** project is to develop Advanced technologies for grading, handling, and packaging autonomously soft and deformable products, as a strategic instrument to improve the flexibility, agility and reconfigurability of production and logistic systems of the European manufacturing companies. In particular, the following points can be highlighted:

- 1) **Product-Oriented Traceability Solution:** communication and control architectures capable of dynamically integrating different control functions and data analysis are being developed. These include the more technical functions related to the product and its quality characteristics, covering traceability, factory management, supply chain system and end customer relations.
- 2) **Data-Driven Digital Twin and Simulations for Production and Handling Synchronisation:** Traditional modelling and simulation approaches are not suited to handling sharp increases in changing customer demands. As a possible solution, the consortium is working on a data-driven framework for the automated generation of simulation models as the basis for digital twins for smart factories. The novelty of the proposed framework is in the data-driven approach that exploits advancements in machine learning and process mining techniques, as well as continuous model improvement and validation.
- 3) **Automated Planning and Line Optimisation:** integration of Data-Driven Digital Twin with production monitoring methods and tools for scheduling optimisation, to ensure constant review of the production programme, its optimisation and robust performance in response to process variability and frequent changes in workload conditions.
- 4) **AI for Rapid Reconfigurable Production and Handling systems:** the project aims at developing a Smart Reconfigurable machine that has the capability to change autonomously, with the intelligence to know when and what to change. This represents an advancement of Cyber-Physical System maturity, from basic operation to analytical insight, decision support, and ultimately self-optimization.

The development of the **AGILEHAND** Reference Architecture (**AGILEHAND** RA) will be for all industrial companies a strategic tool using cutting-edge and industry-specific technologies. This document represents the first deliverable 3.1 "*Reference Architecture*" of the WP3 and is dedicated to the design of an architecture to develop the mentioned solutions.

This reference architecture used by the **AGILEHAND** project is not starting from scratch. A set of previous investigations are implemented by the consortium taking into consideration different relevant and suitable initiatives. Today, different partners are providing their contributions concerning the acquired knowledge on the subject, so that it can be considered as a solid platform to transfer the appropriate knowledge.

In this context, that document highlights an overview and introduces a deep analysis of the most recent developments of some standard reference architectures.

Deliverable 3.1 is made up of different sections, as follows:

After the first section focused on the methodology description, the second section will analyse the experiences and knowledge relevant to **AGILEHAND** that have been obtained from other previous European projects.

The third section investigates standards, platforms and tools that will be analysed to help researchers to determine the best structure for the reference architecture.

To pursue the objective, a version of the AGILEHAND RA is introduced in this report: it specifies a AGILEHAND reference model for manufacturing in terms of layers and levels.

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 AGILEHAND tools.

Document structure

Chapter 1. Methodology: The idea of Reference Architecture will be described in this section, in accordance with many reference standards. More in Depth, the ISO/IEC/IEEE 42010 "*Systems and software engineering - Architecture*" standard is used to conceptualize the AGILEHAND Reference Architecture (RA). The procedure used to fine-tune this deliverable will be also specified.

Chapter 2. Background and Overview: in this section, the context of the deliverable will be considered, with particular attention to the industry sector. The whole life cycle, from cradle to grave, will be considered with the aim to increase the sustainability and resilience of machinery manufacturing companies. An overview will also be provided by including the strategic and relevant solutions applied in different EU contexts within the framework.

Chapter 3. Reference Architectures and relative practices: The chapter aims to investigate the most common reference architectures in the manufacturing domain, such as IIRA (mainly), RAMI4.0, IDSA and IMSA.

Chapter 4. Reference Architecture of AGILEHAND: this section is devoted to the AGILEHAND Reference Architecture (AGILEHAND RA).

Chapter 5. Conclusions and further measures: conclusions and potential measures to be undertaken and planned for the coming periods.

1. Methodology

The conceptualization of a system's architecture, as described in the ISO/IEC/IEEE 42010 "*Systems and software engineering - Architecture*" (ISO.ORG, 2011) standard, aids in understanding the essence of the system and important characteristics relating to its behaviour and composition.

It explains the structure of the system and its constituent elements, as well as how the system interacts with its surroundings. RAs are employed as general recommendations that abstract from the particular requirements and technological landscape of different implementations and use cases:

- A shared lexicon that makes conversation easier.
- A shared architectural vision that unifies and concentrates the efforts of several individuals and teams.
- Modularization, which divides the effort and creates a supportive environment for later integration.
- Baselines and direction.
- Conceptualization of the domain and realization.

The Reference Architecture of AGILEHAND Solutions presented in this Deliverable is based on the utilization of several concurrent views. Diverse perspectives allow for the handling of the functional and non-functional needs separately as well as the concerns of the numerous AGILEHAND project stakeholders, technical and business partners.

According to the definitions in the ISO/IEC/IEEE 42010 (ISO.ORG, 2011), the term "*architecture*" refers to the fundamental concepts or qualities of an entity.

A set of standards, methods, and principles known as the Architecture Framework (AF) are used to describe architectures that have been developed within a specific application area or group of stakeholders. This AF considers a collection of norms for the production, interpretation, and usage of an architecture perspective that frames one or more concerns held by the system's stakeholders. A correspondence rule that names or identifies connections between two or more architectural description elements may be present in the AF. To this purpose, a model type is a class of models that can be identified by their salient traits and modelling regulations.

The entities stated above are graphically depicted in Figure 1 by including their inter-relationships.

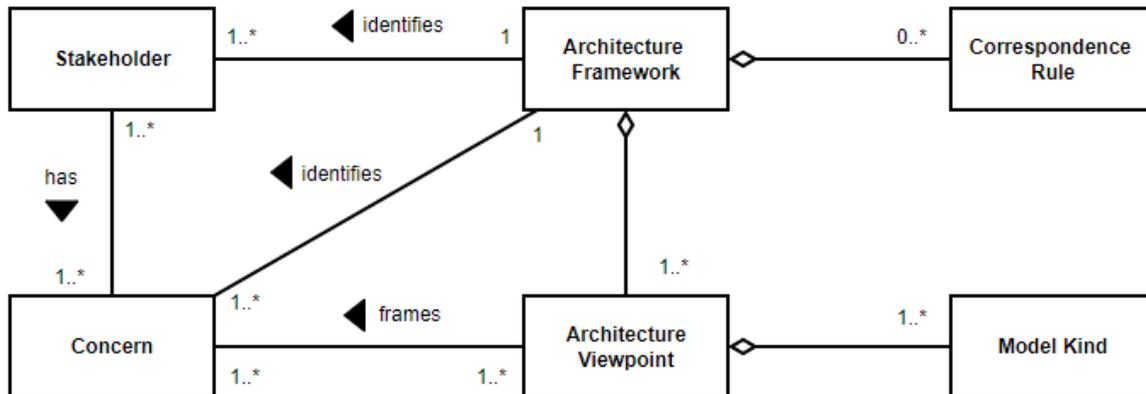


Figure 1. The entity model for the Architecture Framework in ISO/IEC/IEEE 42010

The main relevant viewpoints stated in the context of the **AGILEHAND** Architectural Framework are the following: Business View, Usage View, Functional View, and Implementation View.

The above-mentioned methodological approach will be used throughout the creation of the **AGILEHAND** project's reference architecture. In-depth, many existing Reference Architectures in the community, as well as alignments and definitions identified in manufacturing, will be better considered in the coming sections, respectively 2 and 3.

2. Background

2.1. Project Background

Market evolution and the rapid change of consumers' needs have highlighted the imminent disappearance of many mass production methods (Zhang & Ming, 2022) in favour of new solutions that are able to quickly respond to spontaneous needs and trends. While a great deal of research is being carried out in this direction on production systems, it is also necessary for workpiece handling and, more generally, in-bound logistics systems to evolve to become easily adaptable to different goods, more quickly and efficiently. Such a system must be reconfigurable, i.e.: integrated, convertible, scalable, and customisable. It is therefore necessary to develop technologies and algorithms for designing and controlling reconfigurable production and logistics systems.

In terms of revenue, the **conveyor system** market was valued at US\$ 7,940.38 million in 2019 and is projected to reach US\$ 11,903.88 million by 2027; it is expected to grow at a compound annual growth rate (CAGR) of 5.5% during the forecast period from 2020 to 2027 ([reports/conveyor-market](#)). Europe plays an important role in this sector, covering 23% of the market. Based on industry, the food & beverages segment is expected to be a leading segment in the global conveyor system market during the forecast period. Advanced conveyor systems are broadly used in the food & beverages industry in order to enhance food quality, productivity, operational efficiencies, and safety.

The **robot segment for the automated material handling** equipment market continues to dominate the market size for installed automated material handling equipment. It is expected to grow at a CAGR of 12.0% from 2021 to 2026. Therefore, the material handling robotics market value would rocket up to USD 52.39 billion by 2029 ([reports/material-handling-robotics](#)). To meet stringent demands and stay competitive amid the global pandemic and beyond, a growing number of manufacturers are implementing more affordable, versatile and agile robots to optimise operations. This is especially true for material handling applications like assembly, picking, packing, palletizing, part transfer and machine tending. The European region can play a role in the material-handling robotics market. This is because of the increasing expenditure for research and development proficiencies, the presence of major key players in the region and rising awareness related to the material handling robotics.

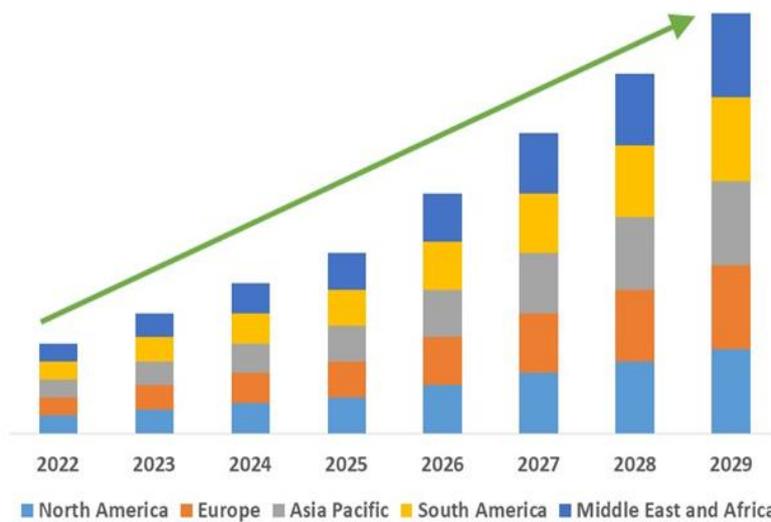


Figure 2. - Global Material Handling Robotics Market, by regions, 2022 to 2029

Although techniques that allow robots to handle rigid objects have become increasingly advanced over the past few years, strategies for grasping these objects do not always transfer well to deformable objects (Huang et al., 2021). For instance, while a soft toy could be grasped haphazardly, a rigid object that does not conform to a user's hand might require a steadier and more precise grasp. Similarly, while a rigid food container could be grasped strongly and decisively if it were more flexible then a robot would need to be more careful to avoid crushing both the container and the food inside it. Most objects in the real world, including food, clothes, bottles, or plastic items are deformable, which essentially means that they can easily change shape while someone is manipulating them. In addition, there may also be applications of these technologies as surgical robotics. Training robots to grasp both rigid and deformable 3D objects is a crucial step towards the employment of robots for a variety of real-world applications, including food processing, robotic surgery or household assistance.

2.2. State of the art of European Projects on equipment development for boosting agility, sustainability and resilience in the industrial sector

AI-based solutions are utilized as a strategic tool to improve the flexibility, agility, and reconfigurability of manufacturing and logistics systems, and as a result, their sustainability, for automatic grading, handling, and packaging of soft and deformable products. To combat the challenges of global competition and improve the performance and sustainability of the high-added-value food products business, the production line of the chosen industrial processes must be integrated with AI-based technologies.

Many initiatives stemming from European projects have been made in the AGILEHAND area and will be covered in the parts that follow.

AI-PRISM

Background

AI-PRISM¹ project (2022) intends to create an ecosystem of human-centric AI-based solutions for challenging-to-automate manufacturing scenarios that demand quickness and adaptability. Because of its programming-by-demonstration modules, the ecosystem will be integrated and scalable with installation-specific solutions for collaborative and semi-automated manufacturing in flexible production processes. The ecosystem will consist of four main pillars:

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

The programming of collaborative robots for complex tasks is one of the main challenges for their application in the workplace, especially for SMEs.

Robots implemented in the AI-PRISM Projects are created to learn difficult procedures by watching human operators carry them out to get over obstacles. Making programming a new task a simpler procedure that doesn't require complex programming knowledge, will offer SMEs a profitable cheap option. The robots created by AI-PRISM will learn through observation, just like a craftsman's apprentice does. Real operational environments in four pilot projects are used in key manufacturing sectors: Furniture (ES), Food/Beverage (GR), Built-in Appliances (TR) and Electronics (PL), with aims to evaluate the performance, transferability, scalability, and large-scale deployment of applied solutions.

Principal Characteristics

The goal of the AI-PRISM project is to introduce AI-based solutions in order to improve the state of manufacturing processes. The goal is to increase the manufacturer's productivity at all levels of the hierarchical structure and, in turn, customer satisfaction levels. AI-PRISM will give advancements in various fields to accomplish its objectives.

Collaborative Robotics in Smart Manufacturing

Cobots, also known as collaborative robots, are being employed more frequently in industrial settings because of their capacity to react to unanticipated occurrences, direct interaction with other shopfloor workers, and safe design. These robots can boost productivity, economy, and spatial efficiency while protecting floor personnel. For humans and robots to cooperate safely and effectively in these collaborative circumstances, Human-Robot Interaction (HRI) techniques or

¹ [AI-PRISM – AI-Powered Human-Centred Robot Interactions for Smart Manufacturing \(aiprism.eu\)](https://aiprism.eu)

systems must be used. In industrial settings, this could result in the accomplishment of tasks that call for a blend of human and robot expertise.

AI Tools to Enhance Perception, Reasoning and Control Capabilities in Collaborative Robotics

To produce real-time knowledge of human emotions, behaviours, and intentions, an extensive and calibrated network of sensors will be constructed for AI-PRISM. The system will employ machine learning methods to create semantically annotated spatial points from signals coming from a range of environmental sources. To digitally model unknown objects and behaviours, more details from structured knowledge and reasoning modules will be included. Mobile sensors will improve perception globally and lower modelling and tracking errors for people. Based on accumulated behavioural data and the changing context of operations and the environment, techniques will be developed to categorize and forecast the future intention of operators.

Robot Programming without Highly Skilled Personnel (Programming by Demonstration)

AI-PRISM aims to exploit the advantages of Learning from Demonstration (LfD) probabilistic approaches to increase the safe motion generalization capabilities in new situations. The project will use the synergy between trajectory parameterized probabilistic principal component analysis (traPPCA), expression graph-based task specification language (eTaSL) and the invariant shape descriptors to learn bounded probabilistic model skill representations. It also aims to provide less intrusive interfaces for expert operators to perform demonstrations without disturbing their craftsmanship. The acquired craftsmanship will be further refined by leveraging supervised and unsupervised learning techniques to increase the manipulation capabilities of robotic systems, resulting in more flexibility and reliability in automating industrial tasks.

Potential interest in AGILEHAND Project

The AI-PRISM project may be useful for AGILEHAND. Due to the primary technology they both plan to utilise, these two projects can have similarities. The development of artificial intelligence tools for process simulation can be based on the models established for learning manual processes using LfD and Deep Learning.

CLARUS

Background

The CLARUS² project connects the sustainable paradigm in the food industry with AI-based applications with the aim of creating a platform with high communications and processing

² <https://clarus-project.eu/>

capabilities, as well as the use of standardized open protocols and data models that will enable resource consumption assessment and traceability for food industry processes. The Clarus project will focus on the lifecycle of the food industry to increase the sustainability of the European food industry using Green Deal concepts and policies. The project seeks to increase the eco-friendliness of the European food business using a problem-solving strategy that emphasizes lowering water, energy, and plastic usage.

By utilizing the advantages of smart technology for data management and processing, the digital transformation of food companies can promote sustainability transformation. While the decision to digitize food manufacturing operations is becoming increasingly evident, establishing greater environmental requirements is not that straightforward. There is often misconception within industrial sectors concerning the steps needed for an efficient Green Transition.

The CLARUS project is closely integrated with the European Green Deal program to address this issue and build a quantitative and standard methodology for developing a sustainable food industry structure and culture that can generate revenue while minimizing environmental damage. The initiative seeks to not only improve resources and logistics through prototype solutions but also to produce a broad contribution through the construction of a Green Deal Index (GDI).

Principal Characteristics

The Clarus initiative (Figure 3) focuses to implement the impact of the Green Deal concept by accomplishing three practical outcomes:

- The creation of a CLARUS Green Deal Index (GDI), complete with calculational procedures, instruments, and data.
- The construction of a CLARUS Data Space, which comprises FAIR data models and Industrial Data Platforms capabilities for edge data management, cloud data management, and data harmonization, transformation and sharing.
- The construction of an AI Toolkit, which includes AI algorithms and trained models that are produced, tested, and validated in the project.

(GDI).

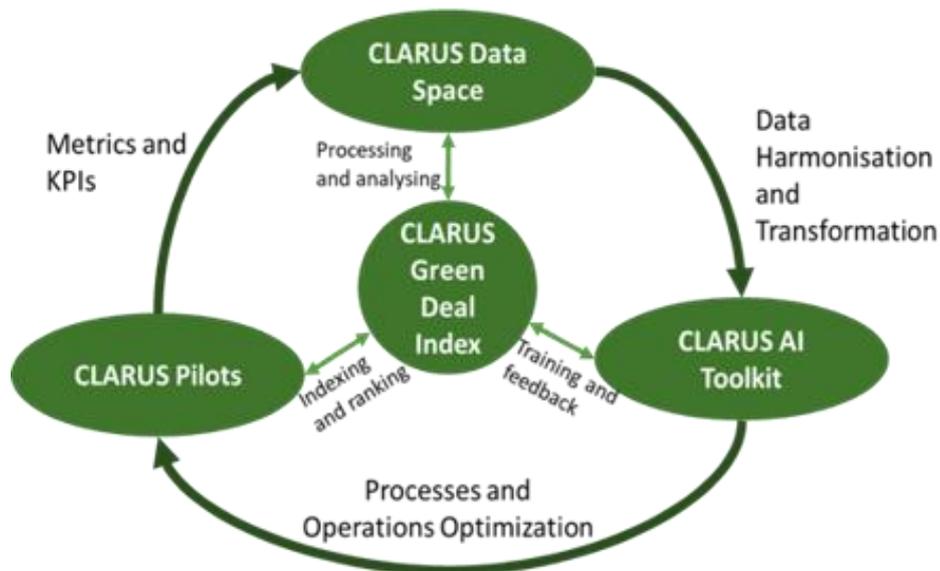


Figure 3. Clarus Approach

Potential Interests in AGILEHAND Project

The Project aims to link standardized open protocols and data models that enable the evaluation of resource consumption and traceability of processes in the food industry. Notably, CLARUS aims to connect the Sustainable Paradigm in the food industry and AI-based applications. It does this by trying to develop a platform with high communication and processing capabilities. In this context, the development of AI in a defined Data Space will help in the definition and creation of a communication standard for AGILEHAND.

TALON

Background

The purpose of TALON is to pave the road for the next Industrial Revolution by developing a completely automated AI architecture that delivers intelligence to the edge in a flexible, adaptive, explainable, energy and data-efficient manner (Figure 4). The architecture of TALON is built on three essential key points:

- An AI orchestrator that works with network and service orchestrators to improve the edge-cloud relationship while boosting the reusability of datasets, algorithms, and models by selecting where each one should be placed.
- Lightweight hierarchical blockchain schemes for introducing new service models and applications while maintaining privacy and security.
- Novel digital twin-enabled transfer learning and visualization approaches that improve AI trustworthiness and transparency.
- It combines the benefits of AI, edge and cloud networking, blockchain, and Digital Twins, which are optimized through the use of new key performance indicators. Moreover, the project aims at developing: a novel theoretical framework, the blockchain used for personalized and perpetual protection based on security, privacy, and trust mechanisms, AI approaches for automatically and co-optimizing edge and cloud resources and AI execution nodes, semantic AI to reduce learning latency and improve reusability, and digital twins that visualize AI outputs.

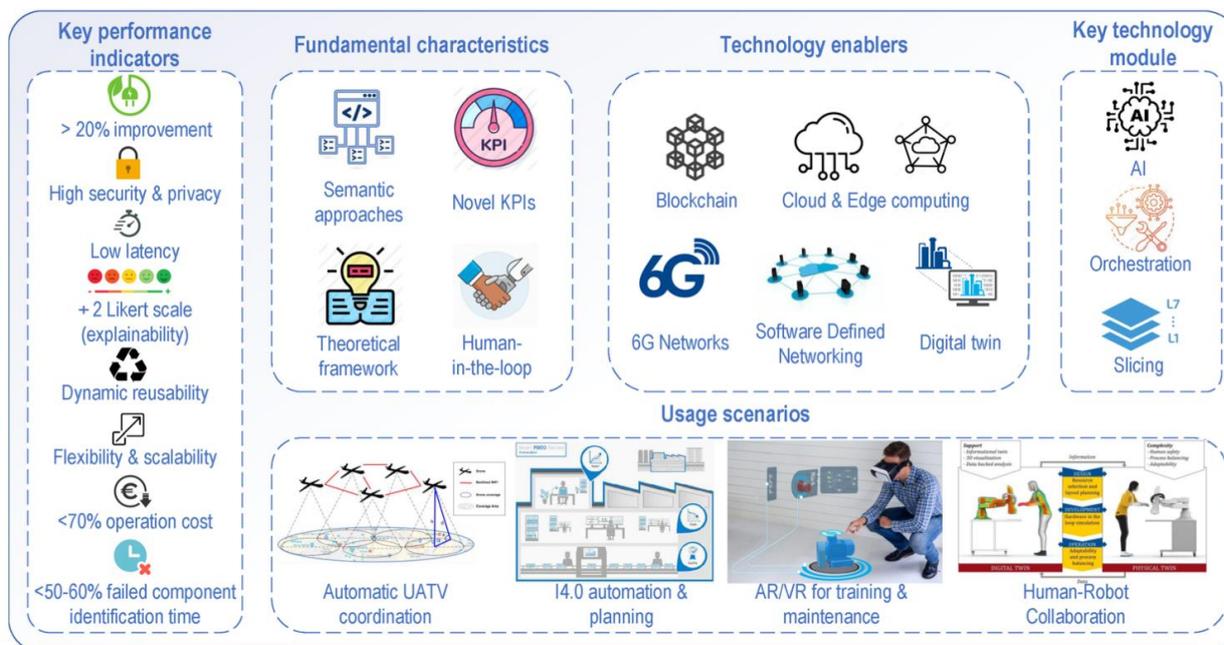


Figure 4. - TALON concept

TALON's strategy also aims to address data privacy and security issues by leveraging blockchain technology and digital twin solutions to assure secure and transparent data management. Finally, TALON's mission is to allow the next industrial revolution by developing a fully automated AI architecture that delivers intelligence closer to the edge while also tackling data privacy, security, and transparency problems in an energy and data-efficient manner.

Principal Characteristics

The primary goal of TALON is to create prototypes and testbeds that incorporate the project's novel concepts, with the goal of promoting the future commercialization of AI products and services based on these principles. To accomplish this key goal, they will concentrate on:

- Implementing and testing the project's technology.
- Putting the project's technology into action and testing it.
- Create patents to protect the main concepts underpinning this technology.
- Push for the necessary interfaces to become industry standards.
- Inform the scientific community about the benefits of the technology.

Potential Interest in AGILEHAND Project

One of Talon's goals is to create an autonomous architecture based on artificial intelligence for deployment on the Edge, with a focus on privacy, security, and transparency. This process entails the development of interface standards and deployment techniques that can be used in AGILEHAND solutions.

C2NET

Background

The C2NET³ project is a cloud-enabled toolkit for SMEs to optimize their supply network of manufacturing and logistic assets. This asset is built on demand, distribution, and manufacturing plans (Figure 5). This project develops scalable real-time software, architecture, and platforms that allow supply network partners to share or store products, logistics, or process data, and collaboratively compute production plans to maximize manufacturing resources.

C2NET is designed to collect data and discover patterns in real time by storing information from both legacy systems and Internet of Things environments. C2NET provides a suite of cloud-based tools to enable collaborative demand-driven optimization of the supply network of logistics and manufacturing assets. One of the goals of the C2NET architecture to make this work is real-time scalability with interoperability.

³ <https://cordis.europa.eu/project/id/636909>

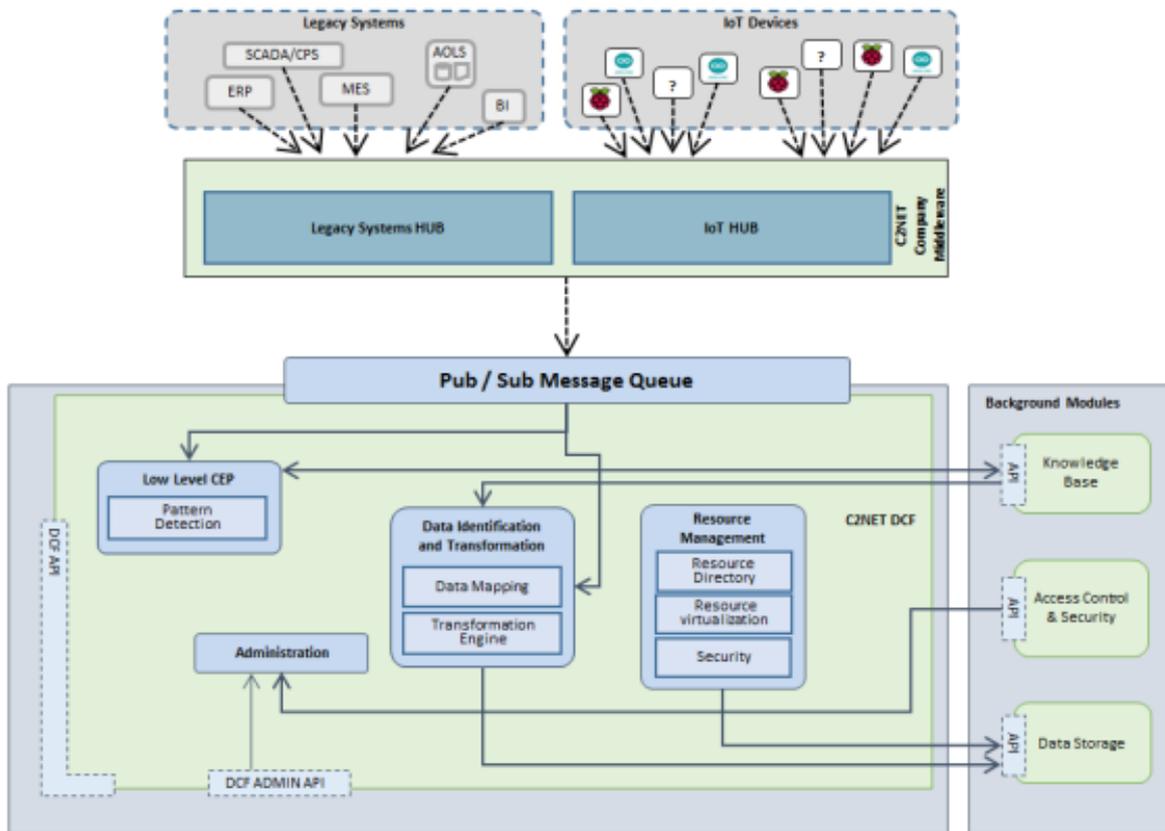


Figure 5. - C2Net Architecture

Principal Characteristics

The C2NET Project's Cloud Architecture is comprised of the following components:

- **C2NET DCF** (The Data Collection Framework): This architecture's IoT hardware and software components rely on continuous data collection from supply network resources. This allows for real-time data collection from multiple physical devices or enterprise systems, providing the C2NET platform with a complete image of the network.
- **C2NET OPT** (The Optimizer): Collaborative production planning to optimize logistics and manufacturing resources to enable industrial networks. This delivers cutting-edge optimization algorithms for concurrent computing delivery, replenishment, and production plans, with a focus on optimizing the use of the supply network's manufacturing and transportation resources.
- **C2NET COT** (The Collaboration Tools): This is a suite of tools that monitors and manages the collaborative process's agility. It contains a real approach to make it easier to diagnose collaborative chain values that differ from any source. These technologies will be able to assist stakeholders in adapting by developing reaction mechanisms based on optimization algorithms.
- **C2NET CPL** (The Cloud Platform): A cloud platform with the many components required to develop a collaborative working environment with network partners is included. It provides users with access to information acquired from many sources in order to create local and global production plans that optimize processes. It accomplishes this through the analysis of data from suppliers, manufacturers, and customers. As a result, it allows for more speedy and effective decision-making, which is crucial given the high level of competition, market fluctuations, and

customization requirements. The C2NET Cloud platform allows for collaborative production. For that purpose, it focuses on acquiring real-time information. This enables it to make supply and distribution decisions for diverse clients or production plans based on real-time data from real resources.

Potential Interest in AGILEHAND Project

One of the features designed for C2NET is that its architecture's IoT hardware and software components are based on the continuous collection of data from network resources. All of this, in addition to tools that monitor and manage the agility of the collaborative process, is delivered via a cloud platform that includes the many modules required to construct a collaborative work environment with network partners. It enables users to construct production plans by accessing information acquired from various sources. AGILEHAND may be interested in all of this in terms of architecture and later reuse of solutions.

Vf-OS

Project Background

Vf-OS⁴ (virtual factory Open Operating System) provides a variety of services for various manufacturing and logistics operations within the firm as well as among the many supply partners. Vf-OS uses a Service Oriented Architecture (SOA) (Figure 6), in which different components are employed to construct different solutions. For data sharing, all the ecosystem's interconnected components provide a REST interface, which is also used by the project's message bus.

Vf-OS is described as an Open Operating System for Virtual Factories deployed in a cloud platform, as shown below. This platform offers services to integrate into manufacturing and logistics processes, as an application marketplace containing many features.

⁴ [Virtual Factory Open Operating System | vf-OS Project | Fact Sheet | H2020 | CORDIS | European Commission \(europa.eu\)](#)

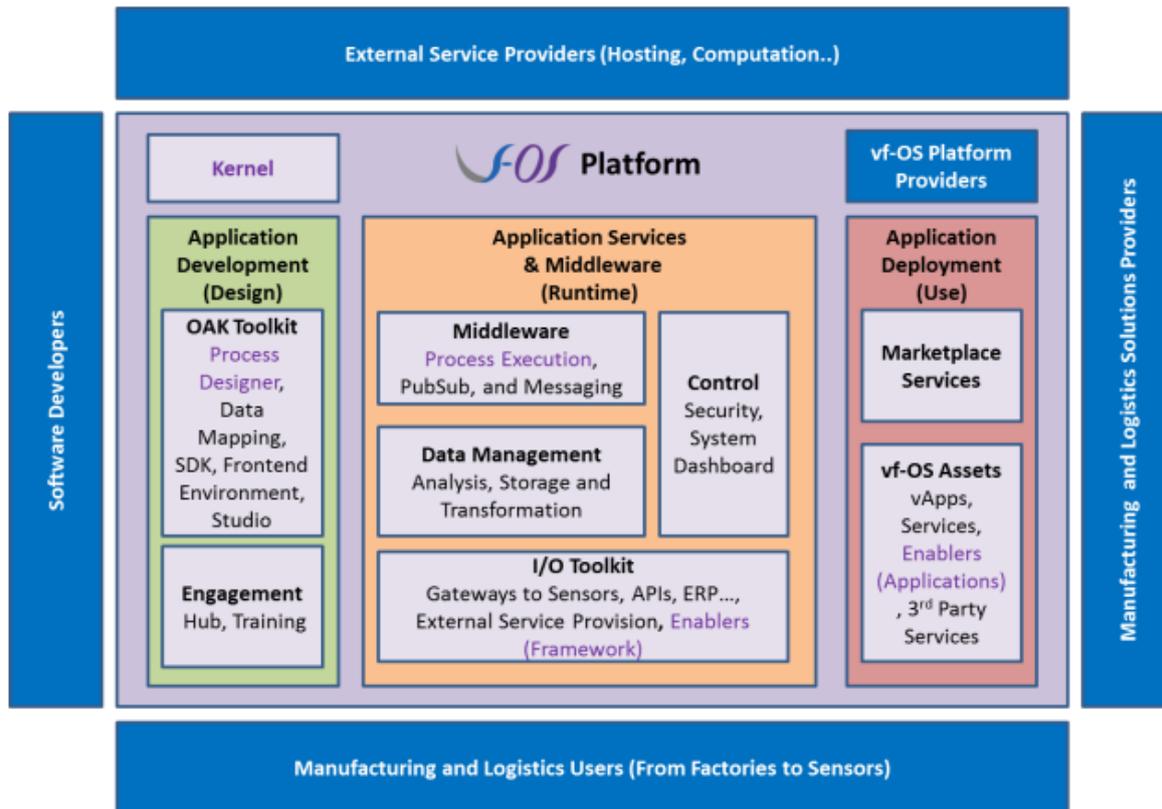


Figure 6. Vf-Os Architecture

Principal Characteristics

The following are the primary Vf-OS features:

- **System Kernel for Virtual Factory:** The Vf-OS kernel is an essential part of the operating system. It optimizes the runtime of processes and applications by utilizing the kernel, a collection of Vf-OS libraries. The kernel libraries implement the operating system's essential functionality.
- **Virtual Factory Device Drivers and Open APIs:** This is a collection of modules linked to virtual images of Vf-Os via a Plug-and-Play method that gives continuous access to the system. Thanks to open APIs, it can securely integrate bridges between manufacturing and Vf-Os applications, allowing access to factory resources.
- **Virtual Factory Middleware and Databus:** This is a collection of modules and smart objects-based cloud data storage (or on-premises). If there are any problems with the cloud-based data warehouse, the sensors will enable data access. As a result, system breakdowns or difficulties are avoided.
- **Open Application Development Kit:** This is a toolset for developing community-oriented applications. These allow it to function in Vf-Os and cover all industry sectors and scenarios. It also allows third-party companies to develop and integrate their specialized applications into the Vf-Os Platform.

- **Cloud Manufacturing Framework:** This is a new Platform with a variety of commercial features, all of which are included in the Vf-Os market and hence monetizable. You can also publish or buy manufacturing apps from third-party providers, which opens up new business options.
- **Virtual Factory Components:** Vf-Os provide a development kit that includes apps and processes for constructing modular components. It integrates seamlessly into the system and with other developed technologies in factories or other projects without producing errors or disruptions in the supply chain.

These traits are founded on the following pillars:

- **Open Source:** By default, Vf-OS and all its components are open sources, allowing software developers and service providers to update them and connect with the Virtual Factory Platform (Vf-OAK) through the Open Applications Development Kit.
- **Sustainable Marketplace and App Store:** With Vf-OS, mobile app shops such as Google Play and Apple Store use a similar concept. It has a virtual shop based on manufacturing-related programs.
- **Joint Exploitation of Project Partners:** Many partners can create numerous components together and assure the sustainability of project results by developing various projects and using cloud platforms.

In terms of platform functioning, four agents can be identified: Service Providers, Software Developers, Manufacturing and Logistics Solution Providers, and Users. Manufacturing and Logistics Customers communicate their requirements to the platform via VF-OAK, and Software Developers use this data to construct new solutions via apps (Fig.7). Cloud services are provided and managed by service providers. Manufacturing and logistics solution providers, on the other hand, test the services to improve the functionality of the apps. As a result, Vf-Os users can employ specified platform apps and incorporate them into their operations, as shown below.

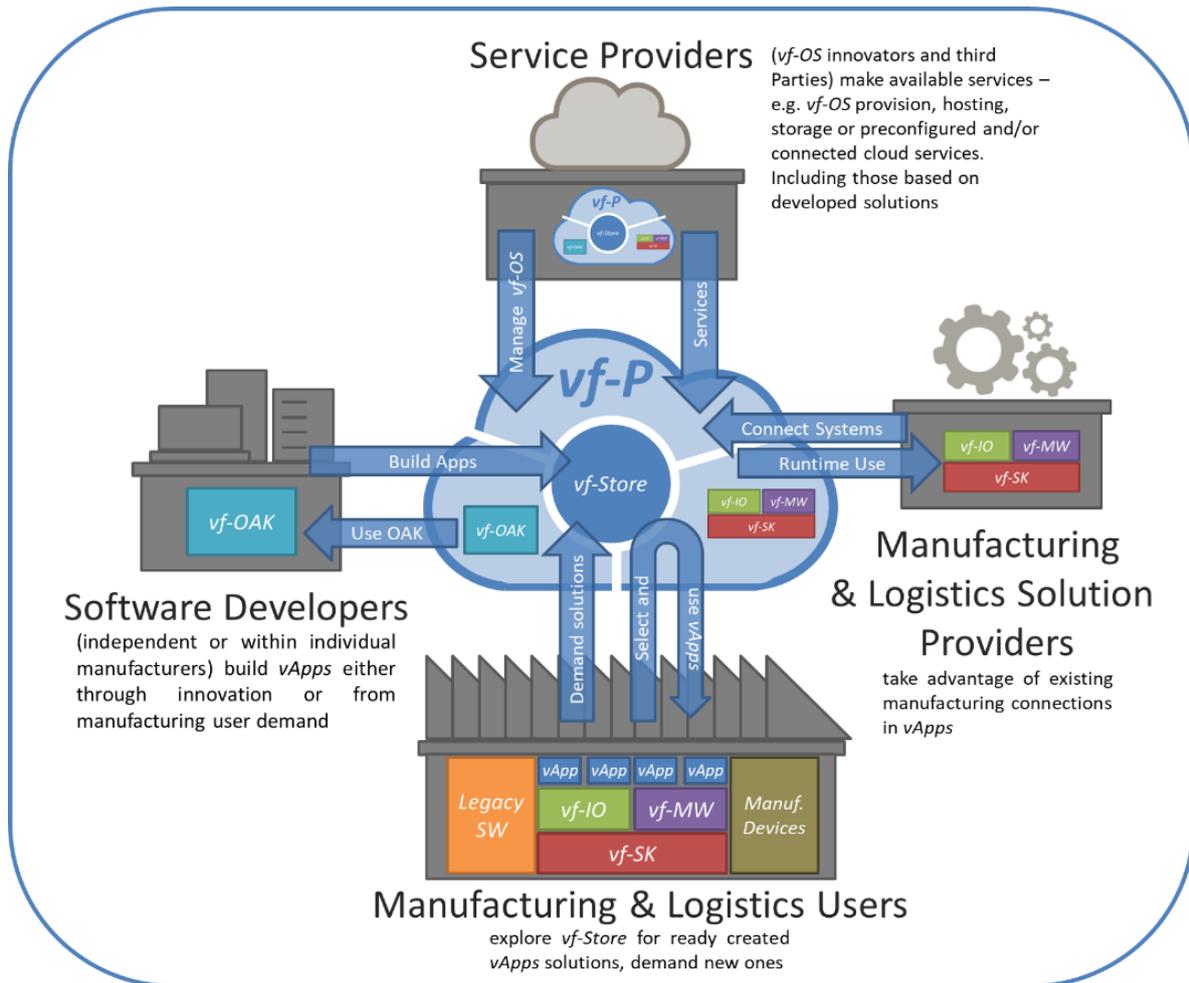


Figure 7. - Vf-Os Approach

Potential interest in AGILEHAND Project

The Vf-Os project's distribution platform proposes an architecture that distributes the use of solutions generated by developers and used by customers that may be of interest to AGILEHAND. This technique enables ongoing development of the solutions developed by all project participants.

DIH4CPS

Background of the Project

The program promotes DIHs for the integration of interoperability in European SMEs' cyber-physical systems (DIH4CPS⁵). The goal was to assist European businesses in overcoming barriers to innovation and to establish Europe as a world leader in the industry. As a result, DIH4CPS established an interdisciplinary network of DIHs and solution providers focusing on cyber-physical and embedded systems, which will intertwine knowledge and technology from many sectors and connect regional clusters with a pan-European group of DIH experts.

The DIH4CPS Network is a long-term network that was created within the I-VLab organization and will continue to operate long after the DIH4CPS project is completed. It creates a unique business model, together with professional operational and sustainability support, to assure the network's overall viability. DIH4CPS validated its ecosystem with 13 initial member DIHs, 12 additional DIHs following the first open call, and seven more following 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, which grew to a total of 23 after successive incorporations.

Principal Characteristics

The DIH4CPS collaboration provides a set of general and operational features:

Overall Feature 1: Improve the Capacity of All European Start-ups, SMEs, and Mid-Caps to Launch New Products Using Modern Digital Technology in the Area of Cyber-Physical and Embedded Systems (CPES). Adoption of digital technologies may be both an opportunity and a challenge for small and medium-sized enterprises (SMEs) and mid-cap companies. The DIH4CPS initiative seeks to assist European start-ups, SMEs, and mid-caps in neglected industries by speeding the creation of new digital products and services, hence increasing competitiveness.

⁵ [DIH4CPS - DIH4CPS](#)



Figure 8. - DIHCPS Architecture

Overall Feature 2: Broaden and Unchain the European Ecosystem for DIHs in Cyber-Physical and Embedded Systems (CPES), (Figure 8). Individual solution providers in the cyber-physical and embedded systems development fields are faced with complex projects that necessitate customized solutions for their end-users. This often entails integrating components from many manufacturers and technologies, as well as addressing investment costs and business case difficulties. To address these difficulties, DIH4CPS has established a global leader network for applied consultation, research, and development of intelligent cyber-physical and embedded systems, leveraging successful and validated collaboration schemes under a network-wide sustainable commercial model.

Potential Interests in AGILEHAND Project

As a technological end-user, AGILEHAND can benefit from the DIH4CPS network of Digital Innovation Hubs as well as from the ontological DIH portal constructed as part of the project, which can serve as a useful starting point for the AGILEHAND partner network. With its success stories resulting from the 23 application experiments created and the expertise in the recruitment of technology suppliers or consumer partners (end users) acquired in the open calls, DIH4CPS is also able to contribute value.

ZDMP

Background of the Project

The ZDMP⁶ platform was created to offer industries a highly extensible and interoperable solution that aids in achieving the objective of zero defects. ERP and plant systems are integrated by ZDMP,

⁶ [Zero Defect Manufacturing Platform | ZDMP Project | Fact Sheet | H2020 | CORDIS | European Commission \(europa.eu\)](#)

which improves the quality and boosts the production. A multitude of design alternatives is available because of its architecture as shown below, (Figure 9)

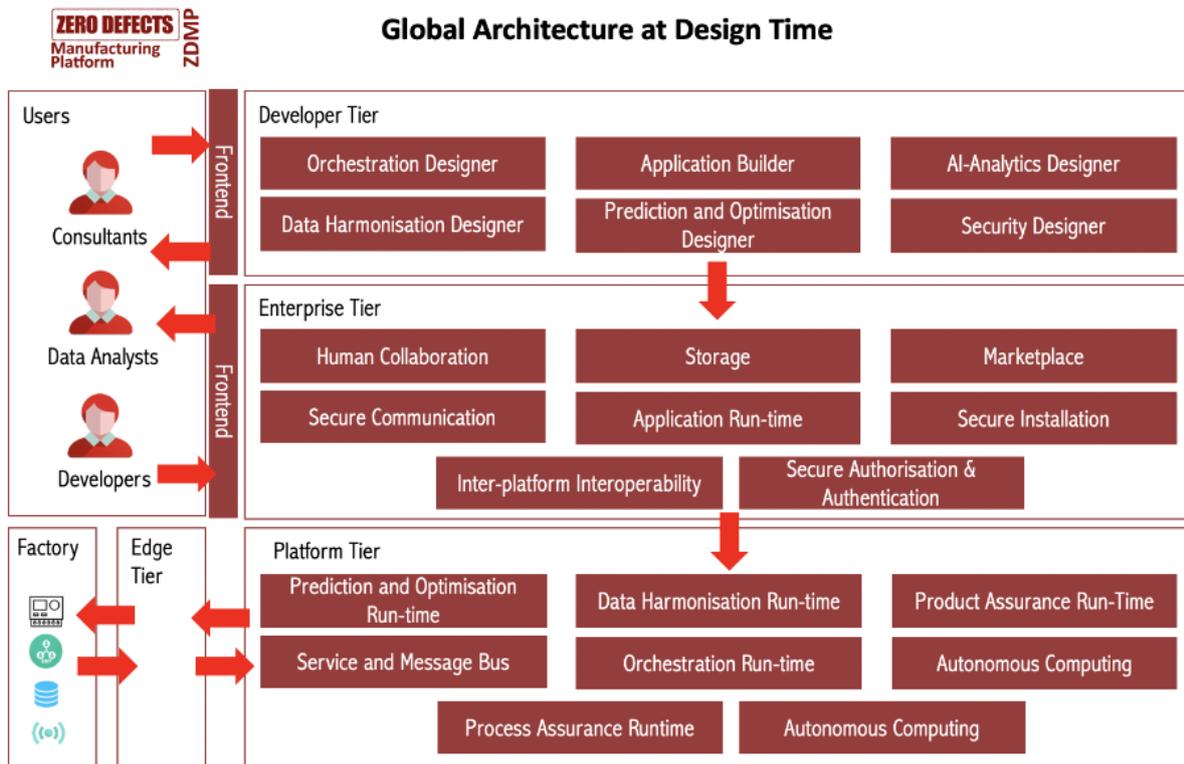


Figure 9. - ZDMP Global Architecture

Users can find programs that are suitable for their factory's needs in the ZDMP app store. The ZDMP SDK (Software Development Kit) additionally enables users or outside businesses to create and include fresh apps within the platform. The SDK gives programmers the equipment they need to do this.

The ZDMP is a four-year project that aims to build platforms for achieving manufacturing excellence through zero-defect processes and products. ZDMP incorporates multiple technologies based on specific principles to accomplish this purpose⁷.

- **Container.** Each ZDMP component is set up to work with Docker. This serves as the platform's foundation for scalability or composability.
- **Extensibility.** Every container comes with an API that enables sharing and platform extension of services. All of this is described in the OpenAPI definition.
- **Diffused Architecture.** Every component function in a distributed manner. ZDMP uses both Kubernetes and Docker Swarm, enabling it to operate in many ways and enhancing scalability.
- **Composability.** Each ZDMP component can be tailored to a particular ZDMP instance, making it flexible enough to fit any solution.

⁷ [Overview | ZDMP \(angry-spence-1ecc9e.netlify.app\)](https://angry-spence-1ecc9e.netlify.app/).

- **Secure.** It includes several security measures (Authentication, centralised authorisation, SSL communication, etc).
- **AI-Driven and Big Data.** It provides infrastructure, models, and tools for Big Data and AI.
- **Connectivity.** It connects to any protocol used by the industry.
- **Developer Experience.** It gives users the means to create new components.
- **Extensible.** Extensions and the creation of new components are both possible.
- **Interoperable.** Via APIs, it can be linked to other systems.

Principal characteristics

The provided features by ZDMP can be classified into two main categories:

- **zComponents:** The ZDMP platform's components offer essential features that can be used by other sources. AI-Analytics Run-time, for example, enables the application of autonomous learning models based on real-time production data, assisting in the prevention of potential errors that could result in losses inside the factory. External platforms can use these ZDMP components to improve their artificial intelligence capabilities and use them in a variety of applications.
- **zApps:** ZDMP platform applications that use both other zApps and ZDMP platform components to provide a particular functionality are known as zApps.

Potential Interest in AGILEHAND Project

With the support of the ZDMP project, industries can achieve zero defaults. Machine learning-based analytical techniques are used to forecast and find these process flaws. For AGILEHAND, this kind of solution would be promising and useful.

On the other side, this platform provides tools for organizing the data that is then fed into the various AI models. The AI Analytics Runtime component was created as a result to make it simpler to provide the infrastructure needed to run AI models automatically. Such tools' capabilities may be useful for deploying AGILEHAND solutions.

I4Q

Background of the Project

The Industrial Data Services for Quality Control in Smart Manufacturing (i4Q) project, which will run from 2021 to 2023, aims to offer trustworthy industrial data services (RIDS) based on IoT through 22 different solutions that can handle the significant amount of industrial data produced by connected, intelligent, and small factory devices.

These solutions provide online monitoring and control of manufacturing. With its five main data cycle capabilities—sensing, communication, IT infrastructure, storage, and analysis and optimization—the i4Q architecture ensures the reliability of data.

As part of an integrated strategy for defect-free manufacturing, the i4Q RIDS will feature simulation and optimization tools for ongoing validation of manufacturing line processes, quality diagnostics, reconfiguration, and certification to ensure high manufacturing efficiency. I4Q architecture is shown below, (Figure 10).

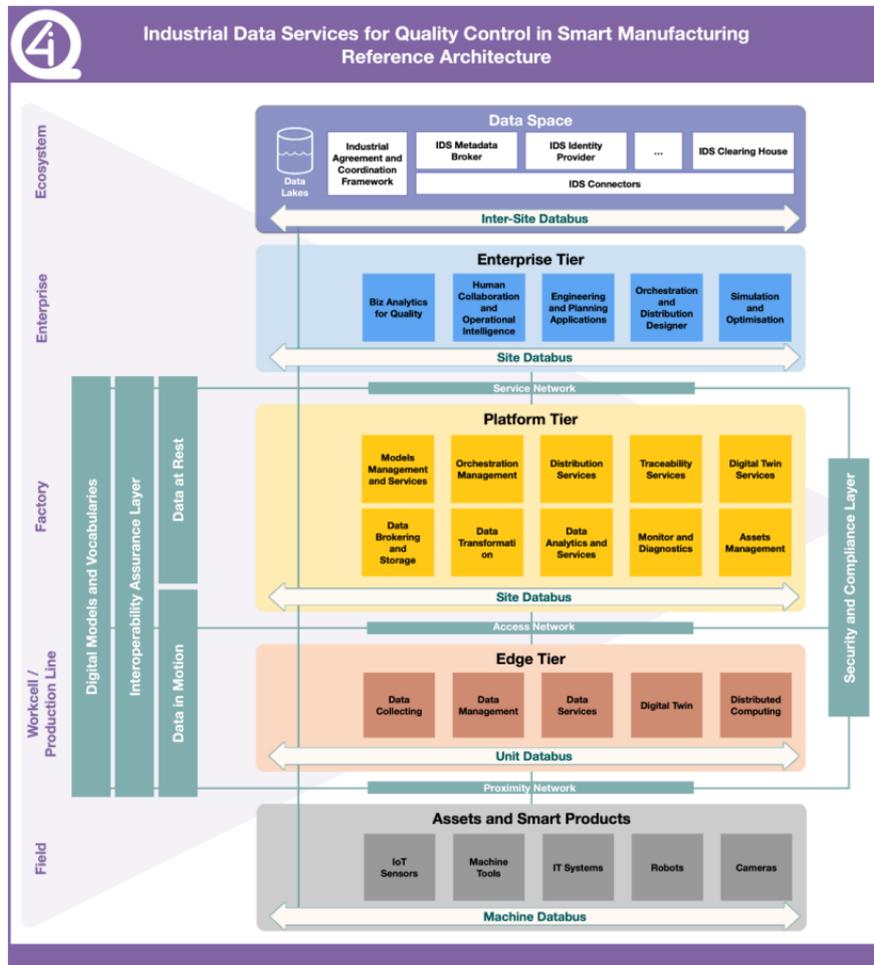


Figure 10. - i4Q Architecture

Principal characteristics

22 i4Q Solutions, 17 software tools, and 5 recommendations make up the entire set of the i4Q RIDS, which is outlined below, (Figure 11):



Figure 11. - i4Q tools.

- Explore for Data Quality Factor Knowledge: is a web-based software program that uses the Evolutional Data Quality Concept and the data life cycle—data collection, data storage, data analysis, data distribution, data use, and data deletion—to visualize information quality characteristics and quality factors.
- i4Q^{DQG} Data Quality Guidelines: this is a comprehensive manual for organizing and carrying out an information flow analysis to determine the pertinent data sources, data storages, communication channels, and data users.
- i4Q^{BC} Blockchain Traceability of Data: provides tools to ensure data trustworthiness and complete traceability, raising the level of trust by using a blockchain-based data service, enhancing trust and acceptability by supplying security and trust in the data that flows directly to the blockchain, acting as a single point of truth, maintaining provenance, and supporting non-repudiation.
- i4Q^{TN} Trusted Networks with Wireless & Wired Industrial Interfaces: this is a type of software-defined wireless industrial interface for data communication that is deterministic and predictable, highly trustworthy, consumes little power, and lowers the cost of installing new wired infrastructure.
- i4Q^{SH} IIoT Security Handler: this is a cloud service that uses a hardware secure module as the trust anchor point to spread trust throughout the architecture.
- i4Q^{CSG} Cybersecurity Guidelines: this is a document that offers a list of recommendations for turning on multilayer cyber security measures in the Industrial Internet of Things (IIoT), allowing IIoT devices to securely communicate with industrial platforms throughout manufacturing.
- i4Q^{DR} Data Repository: is a distributed storage system designed to help businesses that have a high level of digitalization, with most of the production equipment operating as sensors or actuators and producing massive amounts of data.
- i4Q^{DRG} Guidelines for building Data Repositories for Industry 4.0: this is a manual for creating Industry 4.0 Data Repositories, evaluating storage capacity, and creating systems that make it simple to retrieve industry data and interact with microservice applications and industrial platform components.

- i4Q^{DIT} Data Integration and Transformation Services: is a distributed server-based platform with analytical and decision-making capabilities that can get manufacturing data ready for microservice applications to process it effectively.
- i4Q^{DA} Services for Data Analytics: offers a collection of specialized analytical functions and incremental algorithms that can process high-speed data streams analytically and operate on data streams with quick incremental updates.
- i4Q^{BDA} Big Data Analytics Suite: offers a collection of specialized analytic functions and incremental algorithms that can process high-speed data streams with quick incremental updates.
- i4Q^{AD} Analytics Dashboard: is a reporting interface that enables the monitoring of industrial data with completely customizable visualization, drill-down charts, and adjustable dashboards to give users with insightful analytics on a real-time basis.
- i4Q^{AI} AI Models Distribution to the Edge: this is a multi-tier infrastructure designed to manage AI-based workloads in a manufacturing environment with a hybrid cloud.
- i4Q^{EW} Edge Workloads Placement and Deployment: this is a toolset for delivering and executing AI workloads in a Cloud/Edge architecture, which is common in manufacturing plants.
- i4Q^{IM} Infrastructure Monitoring: provides a collection of monitoring tools for orchestrating smart manufacturing workloads and alerting on projected failures, including monitoring the health of workloads and effectively alerting on predicted problems and taking corrective action.
- i4Q^{DT} Digital Twin simulation services: permits industrial firms to create connected 3D production simulations with a digital twin for manufacturing that enables virtual validation/visualization and productivity optimization using pre-existing data from various factory levels (small cell to entire factory).
- i4Q^{PQ} Data-driven Continuous Process Qualification: is a CPQ (Continuous Process Qualification) micro-service that is intelligent and automated and is used to quickly monitor the performance, capability, and stability of manufacturing processes.
- i4Q^{QD} Rapid Quality Diagnosis: is a micro-service that provides a rapid diagnosis of manufacturing line faults, assesses data fidelity, product quality, and process condition, and makes recommendations for maintenance, sensor/data processing recalibrations, and process line/machine reconfiguration.
- i4Q^{PA} Prescriptive Analysis Tools: is a micro-service made up of simulation models as a service that proposes process configuration parameters while taking manufacturing resources, current production planning, and process conditions as inputs.
- i4Q^{LRT} Manufacturing Line Reconfiguration Toolkit: is a collection of optimization micro-services that use simulation to assess various potential outcomes and suggest alterations to the manufacturing line's configuration parameters to meet enhanced quality targets.
- i4Q^{LRG} Manufacturing Line Reconfiguration Guidelines: this is a multi-media user manual for changing the optimisation reasoning principles in accordance with the attained results for line setup, line reconfiguration, and machine parameter calibration.

- i4Q^{LCP} Manufacturing Line Data Certification Procedure: gives recommendations for process reconfiguration, audit strategies, certificates, and regulations. It also provides an audit procedure applied to the manufacturing resources (machine, cell, or manufacturing line) for ensuring that the data resulting from the manufacturing processes are accurate and reliable.

Potential Interest in AGILEHAND Project

The i4Q Project offers us a collection of solutions aimed at enhancing the calibre of a product's production. The solutions can be divided into three primary categories depending on their architectural design:

- (i) data collection and cleaning,
- (ii) analysis of the data obtained,
- (iii) production enhancement based on the studied data.

All these solutions may be intriguing for the AGILEHAND project's life-of-use phase because they enable us to assess, forecast, and enhance the product's quality when employing the machines in various projects.

ZDZW

Background

The ZDZW⁸ project offers a variety of non-destructive inspection technologies that make use of the Internet of Things, enabling accurate assessments of elements that have an impact on product quality across numerous technical fields, such as part integrity, visual requirements, and thermal process efficiency. They provide subscription and pay-per-use models for their inspection solutions, which are affordable and strive to increase return on investment. By emphasizing three key areas, ZDZW aims to reduce defects and waste in manufacturing processes: better monitoring and control for process quality assurance; streamlining rework and repair procedures to recover necessary parts and decrease scrap; and ongoing sustainability evaluation to optimize the use of materials and components across the production line, (Figure 12).

⁸ [ZDZW Project | ZDZW Project \(zdzw-project.eu\)](http://ZDZW Project | ZDZW Project (zdzw-project.eu))

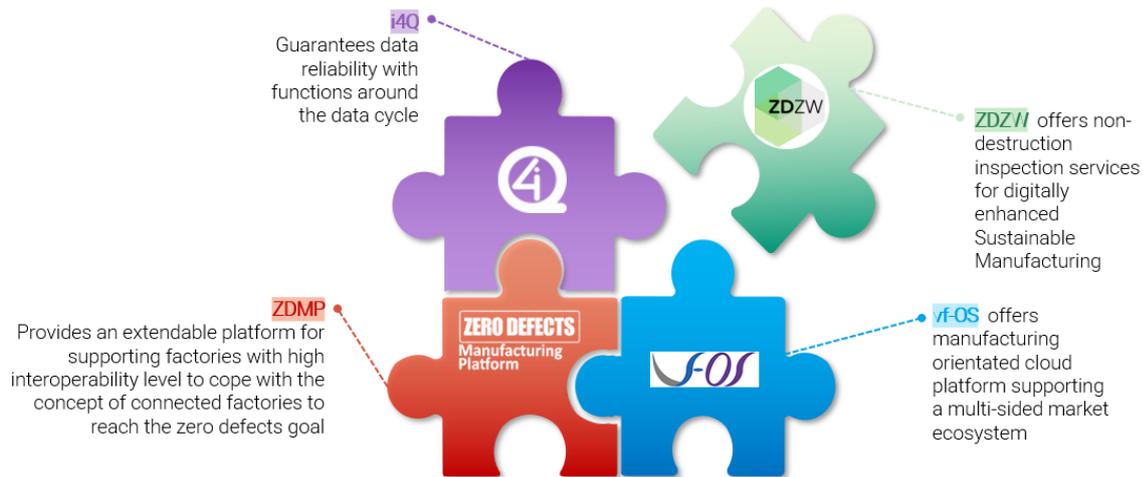


Figure 12. - Synergy between i4Q, ZDMP, vf-OS and ZDZW projects

Principal Characteristics

The ZDMP and i4Q projects' existing parts and solutions, which support the flow of industrial data from collection to analysis, simulation, and quality prediction, are the foundation upon which ZDZW is built. These platforms already offer data security, reliability, and quality solutions that are geared toward the manufacturing industry. ZDZW will primarily use the marketplaces as a platform to exploit generated results and aims to integrate non-destructive inspection (NDI) techniques with the ZDMP and i4Q platforms. By offering cutting-edge monitoring, control, and predictive analytic services based on a variety of NDI systems, training and consultancy services, and sustainability assessment techniques, it acts as a crucial component that strengthens the smart manufacturing ecosystem. To create generic, interoperable, and modular solutions that can be used in a variety of industrial processes, these tools will be tested and validated in specific use scenarios.

Potential interest in AGILEHAND Project

In the use phase of the various machines to be implemented with the pilots, where AGILEHAND has a key role in their implementation, the solutions planted in ZDZW as a subset of the set of solutions offered by ZDMP, i4Q, or vfOS allow us to improve the quality of the products. These all have the potential to increase product quality and decrease waste.

QU4LITY

Background

The largest Industry 4.0 initiative in Europe, Qu4lity⁹ is focused on Autonomous Quality (AQ) and Zero-Defect Manufacturing (ZDM). Via 14 pilot lines, Qu4lity shows how the European industry can develop open, certifiable, highly standardized, SME-friendly, and revolutionary shared data-driven ZDM product and service models for Factory 4.0 in a way that is useful, quantifiable, and replicable. The project demonstrates how a coordinated open platform ecosystem for ZDM and AQ, made up of components and digital tools that cover the full product and process lifecycle, can be used by the European industry to develop highly customized ZDM strategies and obtain competitive advantages.

Building an autonomous quality model is the fundamental objective to meet ZDM's issues in Industry 4.0. Innovative cognitive manufacturing solutions for ZDM may be created, validated, deployed, and adopted by manufacturers and solution providers, including SMEs, thanks to Qu4lity. The project offers digital improvements to current ZDM machinery and procedures in addition to reference architecture and integration plans for enterprises.

Principal Characteristics

The development of the QU4LITY Reference Architecture (Q-RA) for digital ZDM solutions, based on cutting-edge technologies and pertinent industry standards, such as RAMI 4.0, is a challenge in implementing Autonomous Quality (AQ) processes and solutions.

The figure below illustrates the four-tier design of the planned Q-RA. The four basic tiers—Field, Line, Factory, and Ecosystem—are hierarchical and represent the layers of physical manufacturing processes. There is also a Sovereign Digital Infrastructure, which offers shared services including connection and dispersed computing power. Additionally, the Q-RA categorizes system functionality into three distinct functional domains (Adaptive Digital Shopfloor Automation, Multiscale ZDM Cognitive Processes, and Human-Centric Collaborative Intelligence), which are orthogonal to the tiers, as well as three cross-cutting functions (Security, Sovereign Digital Infrastructures, and Digital Models and Vocabularies), which are not specific to any domain. The components, which are self-consistent software modules known as Digital Enablers are what the Q-RA uses to fill the tiers, functional domains, and cross-cutting functions, (Figure 13).

⁹ [About • Qu4lity \(qu4lity-project.eu\)](https://qu4lity-project.eu)

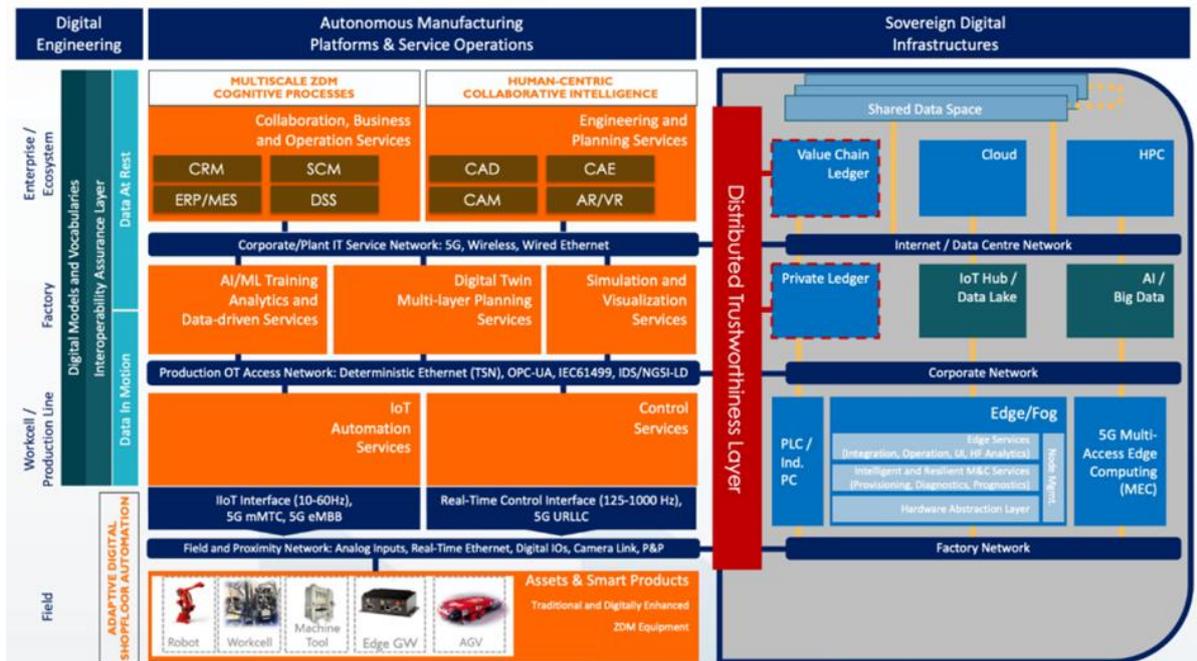


Figure 13. - QU4LITY Reference Architecture

Potential interest in AGILLEHAND Project

Both the Q-RA reference architecture (secure, scalable, and interoperable) and the AI solutions presented in the framework of ZDM are some important elements for the AGILEHAND project.

FRACTAL

Background of the Project

A trustworthy computing node that will enable the development of a Cognitive Edge in accordance with industry standards is what the research project FRACTAL seeks to design and create. This computing node will act as the building block for a scalable Internet of Things, including Edge Nodes with low and high processing power, as shown below. Artificial intelligence techniques are used to give the cognitive capacities (i.e., cognitive), which are supported by internal and external architectures and enable the (platform) node to proactively adapt to changes in its environment, (Figure 14).

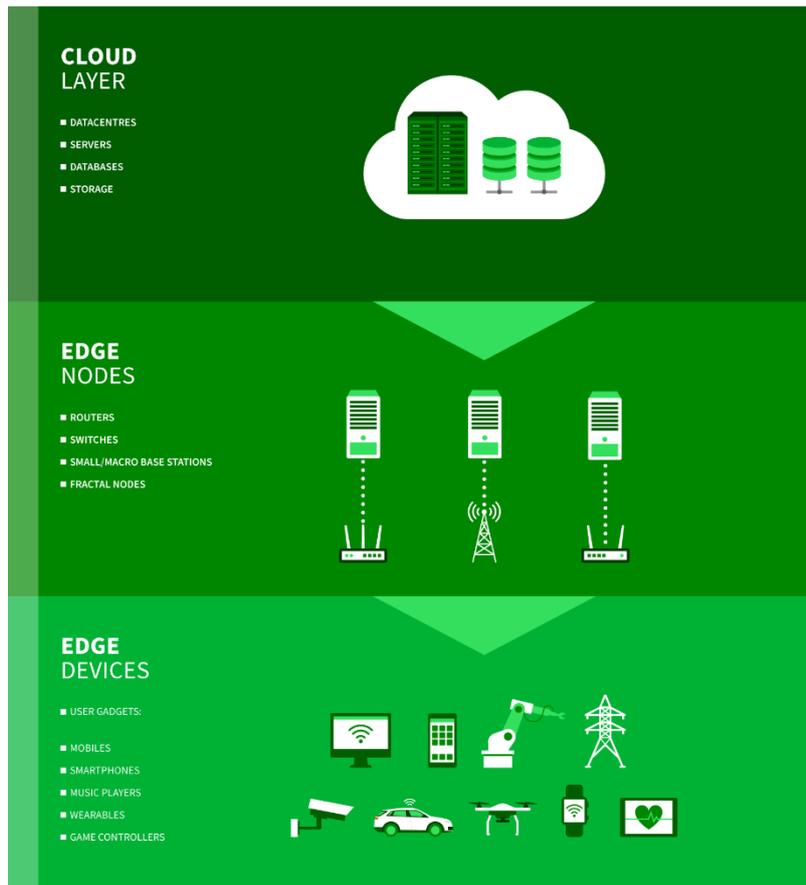


Figure 14. - Edge Fog Computing Layers

Principal Characteristics

The four technology pillars, which serve as the node's necessary components and support the four FRACTAL goals, are listed as follows:

- **I° Pillar: Open-Safe-Reliable and low power node architecture.** With the integration of a significant amount of processing power within Cyber-Physical Systems, this project intends to establish a secure, durable, and energy-efficient hardware platform, leading to the development of a cognitive edge.
- **II° Pillar: Trade-off between low power consumption, security, and excellent performance.** When it comes to performance, timeliness, energy efficiency, dependability, safety, and security, there are many different application domains that FRACTAL looks at.
- **III° Pillar: Cognitive and independent node.** FRACTAL combines sophisticated environmental physics knowledge with AI algorithms to achieve its goal of obtaining a predictive, prescriptive and trusted Edge. By concentrating on using edge technology for control and management tasks, the use of cloud services will be considerably reduced in this way.
- **IV° Pillar: Communications that are mutable and fractal.** To support scaling and a fractal network architecture, this project proposes to include cutting-edge communication (5G) and storage techniques. This covers not only the middleware for information and operational technology

communication but also the methods required for managing and coordinating resources across a distributed network of FRACTAL nodes.

Potential Interest in AGILEHAND Project

FRACTAL presents a framework for moving the AI computing paradigm between the edge of the real world and the cloud, making it an intriguing project for AGILEHAND in the sense of the infrastructure and analytic platform initiatives.

SHOP4CF

Background of the Project

To support people in production activities and provide a basic implementation as a free, open-source solution, the SHOP4CF¹⁰ project aims to develop a platform on an open architecture encompassing technologies based on RAMI 4.0 and FIWARE technologies. The platform's adoption will rely on pilots serving as testing grounds and seeds.

The concept idea is to be able to strike the correct balance between repetitive jobs and cost-effective automation while utilizing human labour in areas like adaptability, creativity, agility, etc.

The coherence and interoperability of the SHOP4CF software components are the goals of the SHOP4CF framework architecture. The architecture offers a standard blueprint for actual systems that are being designed. The ISA-95, RAMI 4.0, FIWARE Smart Industry, and International Data Spaces standard architectures, as well as the architecture of earlier research projects, all adhered to the SHOP4CF design (Figure 15).

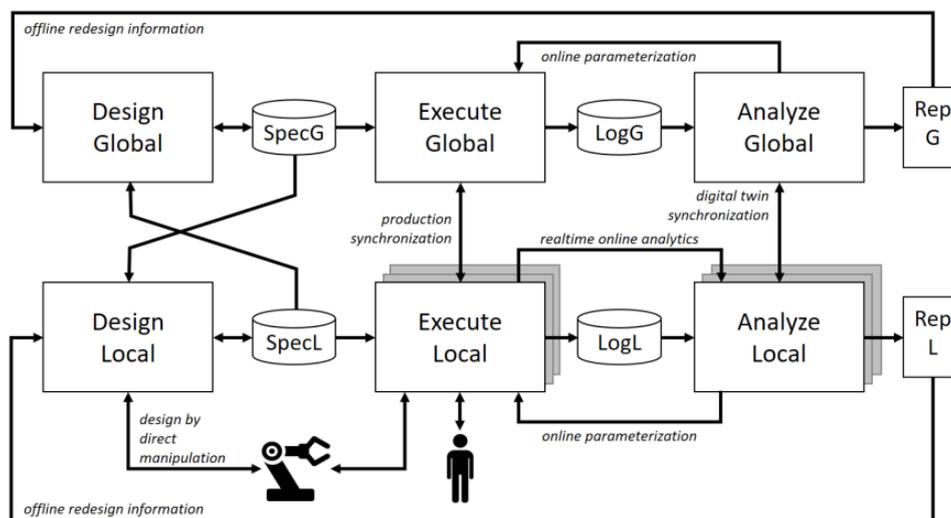


Figure 15. Interface-based high-level logical software architecture

¹⁰ [SHOP4CF * SHOP4CF](#)

Principal Characteristics

The SHOP4CF project creates many parts that support the SHOP4CF architecture's primary functions. The SHOP4CF components include:

- ROS Monitoring (ROS_Mon): Robot system status is monitored via ROS Monitoring (ROS-Mon) to assist personnel.
- Workcell Process Optimization based on Reinforcement Learning (WPO-RL): Reinforcement learning-based process control and optimization.
- The task manager Dynamic Task Scheduling for Effective Human-Robot Collaboration (DTS): encourages secure and fruitful human-robot interaction by assigning robot tasks, tracking their progress, and avoiding a human-robot collision.
- Force-Based Assembly Strategies for Challenging Snap-Fit Components Using Machine Learning (FBAS-ML): Helping human assembly line workers build two or more components that require a snap connection by using a force sensor (force control) on conventional industrial and/or collaborative robots.
- Flexible Task Programming Tool (F-TPT): Robot programming that uses a graphical user interface to swiftly create or modify new control sequences while simultaneously keeping track of feedback on performance.
- Automatic Safety Approval (ASA): This process determines if the selected robot speed is secure and whether the sensor setup can detect objects at the required separation distance.
- Flexible Task Programming Tool (F-TPT): Robot programming that makes use of a graphical user interface to quickly construct or alter brand-new control sequences while also tracking performance feedback.
- Automated Safety Approval (ASA): This procedure assesses whether the chosen robot speed is secure and whether the sensor configuration can detect objects at the necessary separation distance.
- Review of Risk Analysis (RA): Risk analysis is used to identify hazards and calculate the level of risk for robotic applications.
- Open-source implementation of 802.11 Wi-Fi on FPGA (OpenWIFI): Low latency network connectivity between Wi-Fi-enabled devices allows for real-time control, robot interaction, and sensor data collection.
- The Multi-Modal Multi-Range Communication Platform (M3RCP) makes it easier to integrate IoT devices (sensors/actuators) into a factory shop floor and provides the local wireless IoT communication infrastructure needed to link such devices.
- Wireless positioning system based on UWB technology (Wi-POS): enables safe and manageable use of AGVs by accurately localizing them.

-HA-MRN: Mobile robot navigation with human identification and trajectory adaption in accordance with security and social norms is known as "Human Aware Mobile Robot Navigation in Large-Scale Dynamic Environments" (HA-MRN).

-Digital Twin for Intralogistics (IL-DT): Depending on the amount of analysis, a digital twin is automatically built using a simulation model to address intralogistics difficulties.

-PMADAI: Prediction or prevention of possible failures and events is the goal of Predictive Maintenance and Anomaly Detection in the Automobile Industry (PMADAI). Service and repair planning.

-Visual quality check (VQC): for automatic paint fault identification in the automotive industry: quality surveillance. detection (and perhaps classification) of paint flaws in automobiles.

-Virtual Reality Set for Robot and Machine Monitoring and Training (VR-RM-MT): VR-RM-MT uses remote visualization and monitoring to train and assist human workers in collaborative tasks.

-Multi-Modal Offline and Online Programming Solutions (M2O2P): This solution allows you to program robots both online and offline utilizing input techniques based on human natural actions.

-C2NET Data Collection Framework (DCF): Data collection from the industrial shop floor and ERP systems using the C2NET Data Collection Framework (DCF). Using a Complex Event Processing (CEP) engine for process and data stream analysis.

-Digital Twin - Planning and Control (DT-PC): Runtime control of discrete operations, performance monitoring, and remote visualization.

-Adaptive Interfaces (ADIN): Interfaces that change according to the data gathered from devices used on the production line and the user's profile, abilities, and roles within the system.

-Augmented reality-based manual editor (AR Manual Editor): Mixed Reality (MR) component simulator for operator training in the customized product assembly process, including object recognition, operational sequencing, and AR operator guidance.

-Augmented reality-based teleassistance (AR Teleassist): AR Teleassist enables operators to maintain and collaborate on working processes by facilitating communication between staff and specialists via video streaming.

-Virtual Reality (VR): is used to help workers learn on machines, according to VR Creator (VR Creator).

-Manufacturing Process Management System (MPMS): End-to-end management of manufacturing processes, which includes designing, implementing, and orchestrating them. It also includes dynamic agent allocation, handling of exceptions, and process monitoring.

-AR for Collaborative Visual Inspection (AR-CVI): Providing visual assistance to those performing inspection jobs.

-Web of Things Interoperability Layer (WoT-IL): To increase compatibility, the OpenAPI specification is translated into the "Thing Description" format used by the Web of Things (WoT).

-SHOP4CF: offers a marketplace in addition to the components as a one-stop shop for SMEs (developers and end users) to get crucial services for digital transformation, such as business modelling, technical assistance, access to skills, and funding.

Potential Interest in AGILEHAND Project

The SHOP4CF project develops business applications to facilitate and supplement the work of human workers. Digital twins (DT-CP), adaptive interfaces (ADIN), virtual reality training modules (VR-RM-MT), the data collection framework (DCF), and others are a few of them. The AGILEHAND Suites can be developed using adaptive interfaces.

The manufacturing systems in the use cases for the validation of the AGILEHAND AI solutions can be created virtually using the Digital Twin. Data collection from shop floor equipment and ERP systems will be made easier by the data collection framework.

3. Reference architecture test and international initiatives

A variety of technologies with various purposes are used in various industrial processes under Industry 4.0. While each of these technologies often operates independently with various kinds of programming languages and software, the complexity comes from integrating them as a unified system. Because of this, Industry 4.0 replaces the conventional production process's pyramidal structure, which was based on the ISA 99/IEC 62443 standard, with a networked model that is entirely interconnected by the Internet of Things (IoT). To achieve the convergence of operations technology (OT) and information technology, this point seeks to choose an appropriate architectural framework (Velásquez et al., 2018).

Reference architectures (RAs) are essential resources that give system architects a consistent framework and lexicon. The RAs' design is located at a higher level of abstraction, enabling them to recognize and comprehend the most important application challenges and patterns more quickly and easily. Additionally, RAs make it possible to construct a comprehensive system that considers various architectural vantage points to meet the needs of all stakeholders (IIC, 2019). There are several RAs such as the Reference Architecture Model for Industry 4.0 and the Industrial Internet Reference Architecture (IIRA) suggested by the Industrial Internet Consortium¹¹ (IIC) (RAMI 4.0).

The next sections will detail which architectural models the reference structures follow, the way of communication among different layers, the modality of information managed between different layers, etc.

For each section, further sub-sections are developed according to AGILEHAND's interests and principal subjects.

3.1. Architecture Reference for Industrial Internet (IIRA)

IIRA is an open architecture for industrial Internet systems that are based on standards and is designed to improve industry interoperability and direct the creation of technical standards. Based on the use cases outlined by the IIC, IIRA is a general architecture with a high level of abstraction that supports broad industry applicability. The Industrial Internet Reference Architecture (IIRA) was released by the IIC in 2019 in the document "The Industrial Internet of Things Volume G1: Reference Architecture"; a new version of the IIRA, titled "The Industrial Internet Reference Architecture," was released in 2022 (Pedone & Mezgár, 2018). The IIRA contains architectural concepts, vocabulary, structures, patterns, and a methodology for addressing design issues.

The document defines a framework by adapting architectural approaches from the ISO/IEC/IEEE 42010-2011. It identifies the fundamental architectural constructs and specifies design issues, stakeholders, viewpoints, models, and conditions of applicability.

¹¹ <https://www.iiconsortium.org/>

General Framework

The IIRA uses the same fundamental concepts and elements (such as concern, stakeholder, view, and viewpoint) as those found in the ISO/IEC/IEE architecture description specification as its framework for describing and analysing key architectural concerns for IIoT systems.

The views can serve as a jumping-off point for specific architectural design, assisting in the development of an abstract architecture that addresses issues and is then extended and enhanced to meet the requirements of particular use cases in accordance with the requirements of the specific IIoT system architecture (Figure 16).

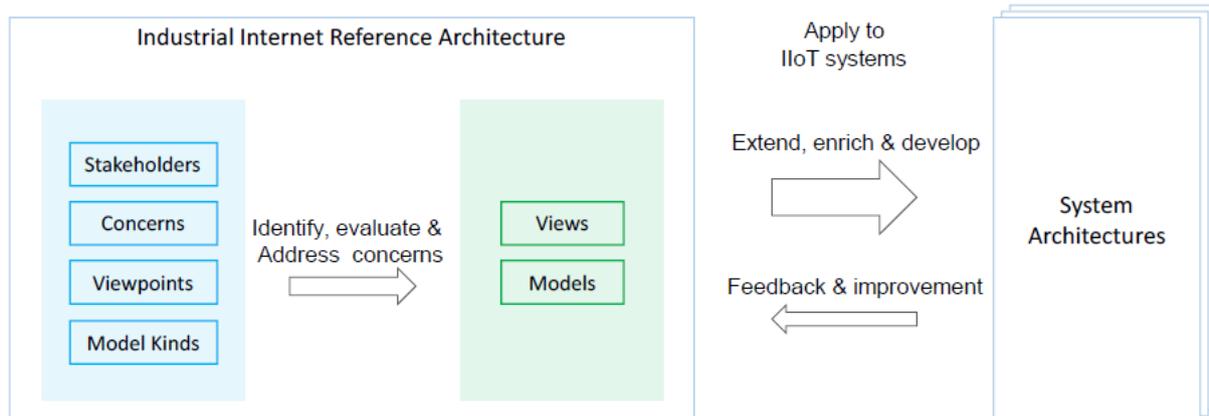


Figure 16. – IIR Architecture and its applications application (IIC, 2022)

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

The mentioned architecture is designed to be a generic background and aims to highlight common architecture models that can be applied to various industrial internet applications across different Industrial sectors. Therefore, it is introduced at a high level of an abstract concept and generalized models. Thus, the broad overview can be customized and expanded to address the requirements of usage scenarios, guiding the development of detailed architectures that address those requirements. To assess the efficiency and utility of the reference architecture in the system-design process, the IIC will compile feedback from actual implementations across a variety of industries, including from various IIC testbed initiatives, and may make revisions and improvements as necessary.

Principal Characteristics

The IIRA methodology is a good tool introduced for a system conceptualization able to help architects and engineers to solve key issues about design for Industrial Internet of Things Architecture. Starting with the structure and layout of an IIoT system, the IIRA design process

considers the perspectives of stakeholders. IIRA viewpoints are developed to accomplish this by analysing various IIoT scenarios from the IIC and other sources, identifying the major players in IIoT systems, and deciding on the best focus for each viewpoint (Figure 17).

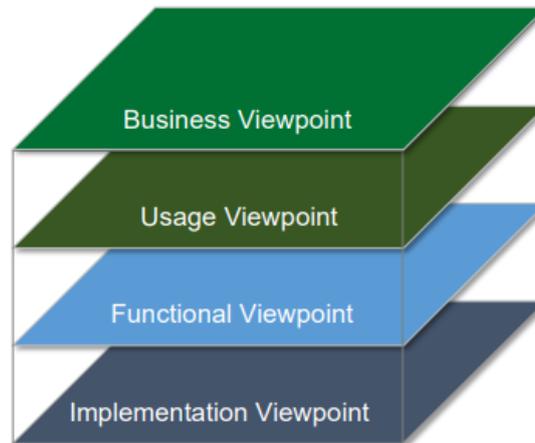


Figure 17. – IIR Architecture Background (IIC, 2019)

The IIRA method provides a structured approach to system design, development, and maintenance. The mentioned perspectives are (IIC, 2022):

- **Business Prospective:** Select the involved sections in the development, implementation of an IoT system, and their business targets. It considers the general business and regulatory environment where the IoT system works.
- **The Operation Prospective:** Focuses on the issues related to the procedures for uses of the system and is generally shown as a list of actions involving human users to give the planned functionality. Stakeholders are typically system engineers, product managers and other similar technicians, including those involved in the specification of the IIoT system and respective users.
- **The Functional Prospective:** Focuses on the purposeful elements in an IIoT system, their shape and interactions and their interfaces, and the relationship of the device with exterior factors in the environment, all to assist the planned uses and actions of the whole system.
- **The Implementation Prospective:** Addresses the issues associated with the technologies, communication structures and lifecycle approach critical to put in force the useful aspects (functional view) and aid the gadget abilities (business view) and things to do (usage view).

The IIRA addresses issues that extend beyond the design level of a system and into its lifecycle as a whole. It drives the IIoT creating process from conception to implementation through its perspectives, which deliver a background for developers and designers to involve the key architectural matters. Furthermore, IIRA suggests common concepts as overviews in each perspective to improve the selection and solve important architectural subjects. Figure below shows the interaction mechanism among several perspectives, from the business to the implementation perspective. The architecture is developed in the logic of layers. After the implementation, the architecture can be modified and finally validated, (Figure 18).

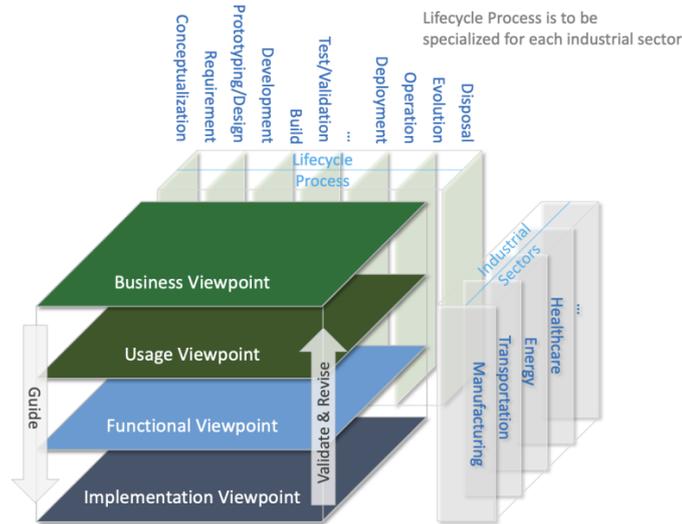


Figure 18. – Interaction among IIRA Perspectives (IIC, 2022)

The functional perspective represents the key aspect in the development and implementation of the IoT system, in line with IIRA.

This perspective divides the system into the selected functionalities, named "functional domains". These are essential components that can be used in several industrial applications. The IIRA specifically devices an IoT system in five functional domains: control, operations, information, application, and business (Figure 19).

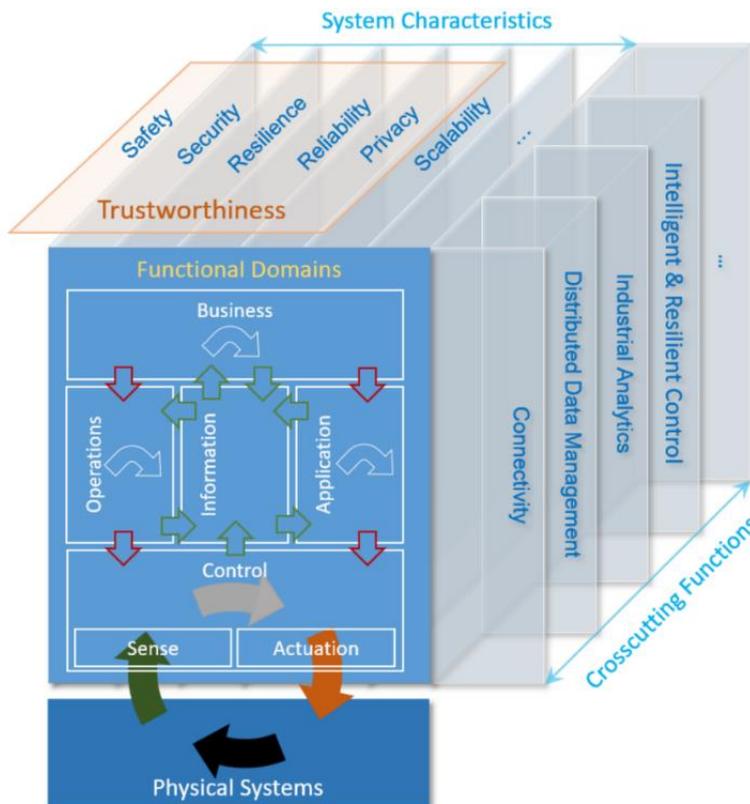


Figure 19. - Functional Domains, Cross-Cutting Functions and System Characteristics as specified in the IIRA (IIC, 2022)

Potential Interests in AGILEHAND Project

The IIRA targets to grant a frequent framework for creating IIoT solutions, enabling companies to greater without difficulty integrate and standardise their systems, decrease improvement time and cost, and enhance their IIoT. Considering that this task is about enhancing the lifestyles cycle of industrial equipment, it is indispensable to have surroundings that let in the interplay of AGILEHAND options with the industrial gear with which it works and ensures the following traits:

- **Integration:** IIRA gives an overview that unites several AI tools for existing industrial processes, such as handling systems, sensors, and actuators. This permits seamless integration and elevated performance.
- **Standardisation:** IIRA affords a standardised structure for growing and deploying AGILEHAND options in industrial environments, making sure of interoperability and compatibility between special structures and technologies.
- **Scalability:** IIRA affords a scalable structure for deploying AI tools to be applied at large-scale industrial environments, permitting deployment at exclusive ranges of granularity. The modular shape of IIRA permits elements to be added, removed, or modified as needed, so the structure can evolve and develop as the industrial surroundings changes.
- **Security:** IIRA gives an ensured architecture for deploying AI tools applied in several industrial sectors, by involving particular requirements and constraints of these industrial environments.

3.2. Reference Architectural Model Industrie 4.0 (RAMI 4.0)

The Platform "Industry 4.0" installed the Reference Architectural Model Industry 4.0 (RAMI 4.0) with a focus on the Internet of Things (IoT) and Cyber-Physical Systems (CPS), especially for the industrial manufacturing sector. To put Industry 4.0 into practice, RAMI 4.0 represents the first critical point. considering all value chains, the model can signify technical items, also acknowledged as "assets". This model's objective is to mirror the technical subjects and all pertinent elements of the system, from its thought and to improve its uses, handling, and applications. The tool additionally shows the step and several interactions that every "Industry 4.0 component" has with other high-level parts.

RAMI 4.0 was like the Industrial Consortium (IIC) that supported Industrial Internet Reference Architecture (IIRA). A unified basis for industrial information and communication technologies, as well as automation and their applications, is what each architecture intends to outline.

Background

Currently, RAMI 4.0 has been efficiently identified in country-wide and global standardization committees and cooperations as DIN preferred (DIN SPEC 91345:2016) and worldwide pre-

standard (IEC PAS 63088:2017). DIN SPEC 91345:2016-04 introduces two simple reference patterns for the Industry 4.0 concept:

- The reference structure pattern RAMI4.0 is a reference pattern for the reference architecture Industry 4.0 and is used for a basic idea's description.
- The reference pattern I4.0 tool is used to increase the access to description concerning the data technology.

Furthermore, a virtual overview of assets is required to define the performance of components in the Industry 4.0 context.

RAMI 4.0 is performed by a system based on 3D coordinate axes: Life Cycle/Value Streams, Layers and Hierarchy Levels, which drives to solve potential trouble of Industry 4.0 in a structured pathway.

RAMI 4.0 ensures a higher understanding among all contributors concerned in Industry 4.0. As a reference structure model, RAMI 4.0 gives the opportunity to discover the standards requested by Industry 4.0 use cases by uncovering practicable cases. This system investigates the methods in suitable measures to decide if they can be suited for potential applications in the Industry 4.0 sectors (Lin et al., 2017). In addition, the potential inclusion of assets and relative digital views is based on a common introduction directly named "Asset Administration Shell (AAS)". Further analysis is listed below by listing each of the introduced dimensions in RAMI 4.0:

- **Life Cycle/Value Stream:** According to IEC 62890, the industrial-process measurement, control, and automation industry includes facilities and products that go through many stages of creation and utilisation. This is represented by the left horizontal axis in the life-cycle management model. In this paradigm, the "types" and "instances" of products are distinguished. An "instance" is the actual product being produced, whereas a "type" is the initial concept and design of a product. The entire life-cycle management process is represented by this model, including all elements and IT components.

Although the Instance section is divided into Production and Maintenance/Usage, the Type section is further divided into Development and Maintenance/Usage. This implies that a product is a "Type" while it is still in the development stage and becomes an "Instance" once it is put into production. A product's state changes to "Type" whenever a new feature or a redesign is made to it. With the capacity to connect logistics, quality, customers, and suppliers with purchasing, production planning, and other departments, lifecycle management offers a clear picture of the value-adding process in fully digital manufacturing.

- **Architecture Level:** An essential part of creating software for Industry 4.0. It has six layers on the vertical axis that represent the virtual mapping of a machine, or the layer-by-layer breakdown of a machine into its attributes. These images come from information and communication technology, where it is common practice to layer the characteristics of complicated systems. This layer makes it possible to consistently construct Industry 4.0 software solutions that integrate various industrial operations that are mutually dependent while also taking into account the physical and digital worlds.

- **Hierarchy Levels:** The Industry 4.0 environment is distinguished by a high degree of automation and connectivity, with an emphasis on streamlining and boosting productivity in industrial

operations. According to the international standards series IEC 62264, hierarchy levels are one approach to depict this environment.

These tiers, which include Product, Field Device, Control Device, Station, Work Centre, Enterprise, and Connected World, illustrate the various functionalities found in factories or other facilities. These features are also represented in the IEC 62243 standard, which is based on ANSI/ISA-95, but with an addition of work components and a connection to the Internet of Things and services. A functional assignment of components and the capability to adhere to IEC 61512 standards at the hierarchical level are additional features of the Industry 4.0 architecture. This axis within a company or factory indicates subsequent phases and describes clusters of factories, and cooperation among outside engineering firms, component suppliers, and customers (Figure 20).

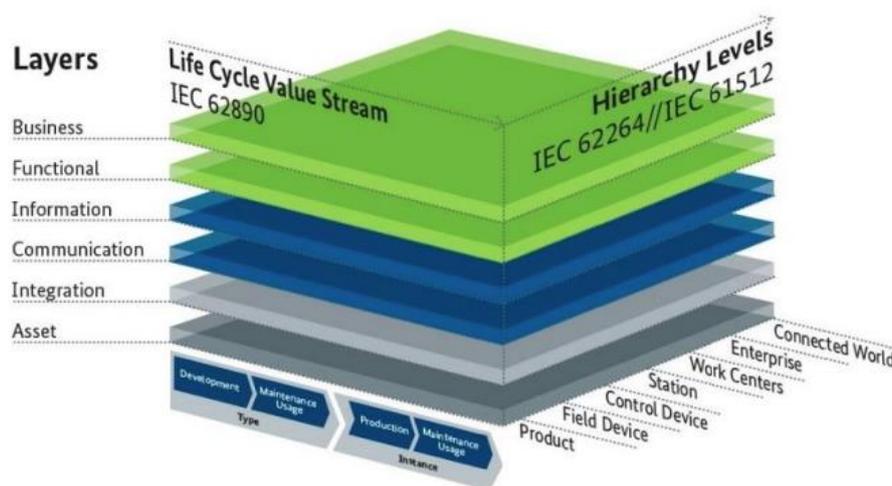


Figure 20. - The three dimensions of the RAMI 4.0 ¹²

Principal Characteristics

RAMI 4.0 provides a reference architectural model that is solution-neutral for 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. This is accomplished by using a common model to frame the developed concepts and technology. RAMI 4.0 provides a framework for mapping industry standards and global demands to define and progress Industry 4.0. It may be thought of as a sort of 3D map of Industry 4.0 solutions. Consequently, discrepancies and overlapping standards can be identified and corrected, (Koschnick et al., 2015).

The 3D matrix allows for the positioning of standards and use cases. Integration within and between factories as well as end-to-end technical and human value-stream orchestration are all handled. This idea is completed by the components of Industry 4.0, which have both been described in (DINSPEC91345:2016-04, 2016). There are six layers on each RAMI4.0 component.

¹² [Reference Architectural Model Industrie 4.0 \(RAMI 4.0\) \(europa.eu\)](http://europa.eu)

The structure is made up of business, functional, information, communication, integration, and asset layers, and is shown below as a layered IT system structure, (Figure 21).



Figure 21. - Architecture Layers of the RAMI 4.0 ¹³

Examining each layer (Fraile et al., 2019):

- Business level: demonstrates the overall procedure, the rules of the system, and the business concept. The business model layer incorporates the value stream's functions. The requirements of the legal and regulatory framework are also described. The business layer, which also receives events that offer updates on how the business process is going, coordinates the services provided by the functional layer.
- Functional level: it offers the runtime and modelling environment to the services that supply the business layer. Remote access and horizontal integration take place in the active layer, except for operations that are purely relevant to lower layers (such as reading diagnosis data) or that are not critical to continuing functional or horizontal integration.
- Informational level: it includes the data services that enable the usage, generation, and upkeep of the data because of the technological features of the assets. Data integrity, provisioning, integration, and persistence are all covered. To make the functional layer services available, it applies the appropriate processing and transformation of events received from the physical assistance through lower-level layers.

Communication level: it provides standardised data and communication formats, allowing for information access and interfaces for using an asset's features obtained from other investments.

¹³ [Reference Architectural Model Industrie 4.0 \(RAMI 4.0\) \(europa.eu\)](https://european-council.europa.eu/media/en/press-communications/infographic/infographic_ram40_en.pdf)

The communication layer focuses on providing the procedures and protocols for the information exchange between components in an interoperable manner.

- **Integration level:** it illustrates the transition from the physical to the digital world. The integration layer displays a representation of an asset's properties and process-related functions while reporting events from the real world. The integration layer also contains asset documentation, software, firmware, or Human-Machine Interfaces (HMI).
- **Asset level:** The component layer focuses on how each contributing component is physically distributed within the framework of the smart grid. This includes tangible things, computer programmes, system actors, written works, ideas, and people.

Asset Administration Shell

The Asset Administration Shell (AAS) is a set of data and resources utilised by a business or organisation to administer a particular asset. Inside the organization's Industry 4.0 network, one can locate and study this body of data that is connected to a particular asset. Furthermore, the AAS manages access to the asset it administers (Wagner et al., 2017). The AAS is available in various implementation variations, including:

- **Passive**, as in the case where data is delivered via a file or by IP/API-based access. In that situation, a client/server pattern is used to deliver the needed AAS.
- **Active** that is peer-to-peer interaction model. The Industry 4.0 language can be used for communication between the administrative shells.

AAS implementation can be assigned in the RAMI4.0 Model starting with the classification, covering many layers, (Figure 22). RAMI4.0 can be used to demonstrate the differences between passive and active AAS. The passive administration shells offer descriptions of the characteristics, parameters, variables, and process capabilities in the form of so-called sub-models. This abstraction of assets is accessible, readable, and modifiable by other components. Passive characteristics of this kind of AAS include the capacity to comply with requests and instructions from external sources and the incapacity to take the initiative and make decisions to promote one's own goals. Furthermore, the term "active" refers to the independent activation of interaction with outside AASs, such as when pursuing a goal, (Belyaev & Diedrich, 2019).

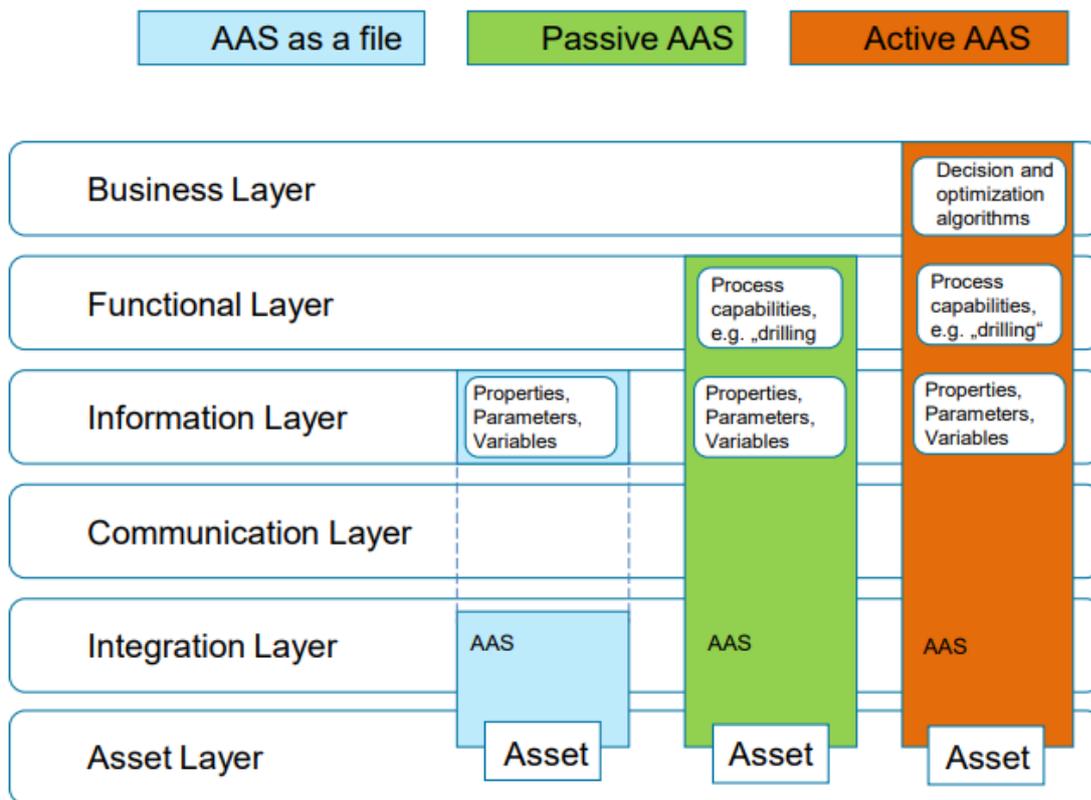


Figure 22. - Assignment of the active AAS in the RAMI4.0 – Model (Belyaev & Diedrich, 2019)

A resource is anything that can be linked to create an Industry 4.0 solution (i.e., machinery, parts, supply material, documents, contracts, etc.). Together with data models for information exchange between value chain actors, the AAS also specifies a package file format (the Asset Administration Shell Package, or AASX) for transmitting all or part of the administrative shell's structure, (Figure 23), (Fraile et al., 2019).

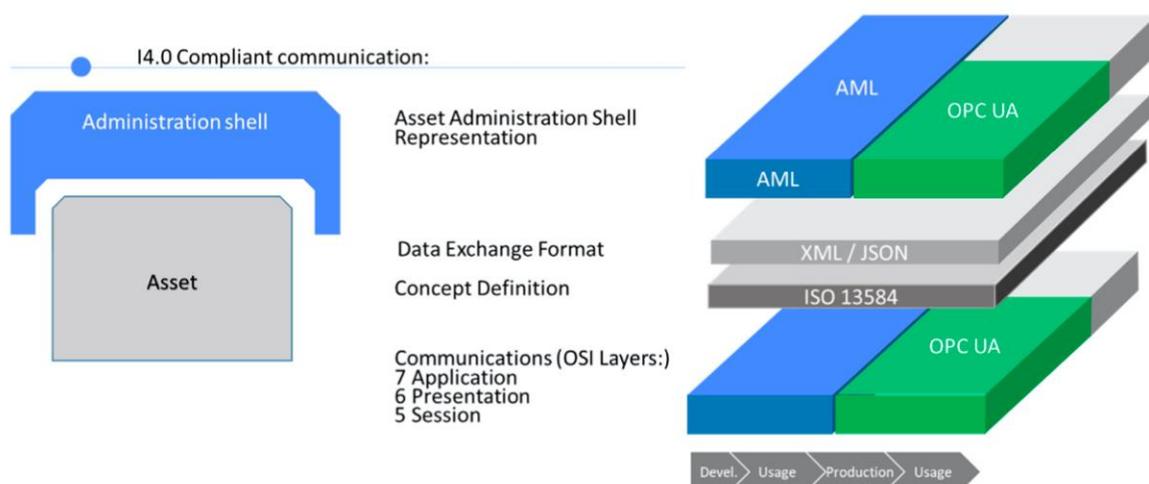


Figure 23. - I4.0 Communication protocol stack.

The AAS implements the Digital Twin idea, guaranteeing:

- **Interoperability**, allowing businesses to connect and exchange information.

- **Availability**, for any type of product (non-intelligent and intelligent).
- Value chain **integration**.
- **Spanning** the whole life cycle of products, devices, and facilities.
- **Principle** for autonomous systems and AI.

Potential Interests in AGILEHAND Project

RAMI 4.0 makes it possible to discuss various use cases, standards, or end-user viewpoints while considering all the parties involved in industrial production. AGILEHAND can investigate the various points of view considering all these viewpoints for this aim. RAMI4.0, on the other hand, supports several standards at various tiers. OPC UA, for instance, can be used for the communication layer (Although companies can use unofficial or internal standards). The AGILEHAND project and its Reference Architecture will benefit from this element related to data models and communication flexibility.

3.3. IoT Reference Architecture ISO IEC 30141

The Internet of Things (IoT) - Reference Architecture standard, ISO/IEC 30141:2018, defines a uniform nomenclature for building and developing IoT applications. This standard, which is related to developments and digital transformation, provides the sector with a useful road map, a common vocabulary, and reusable design elements.

Background

A detailed architectural and structural framework that specifies a methodical procedure for developing IoT systems is provided by the IoT RA. Its objective is to improve the understanding of IoT systems among key constituencies such as device makers, app developers, consumers, and users. It also acts as a manual for architects creating IoT systems. The following figure shows the Conceptual Model. It shows a list of traits that characterise a Reference Model (RM), and one or more architectural views are used to create the IoT RA, (Figure 24).

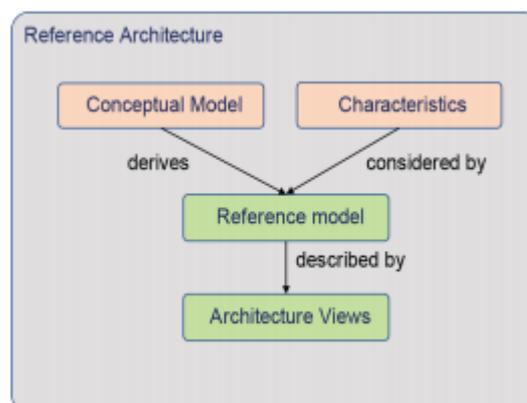


Figure 24. - IoT RA structure (ISO/IEC 30141:2018)

Characteristics

IoT systems can implement functions based on all or some of the features. Some of these traits (like network connectivity) are functional, whereas others (like availability and compliance) are not. The actual quantification of these features can vary depending on the application specialization. An IoT architect must still consider how important each category is to the system being created. Any IoT system can have any number of attributes.

Theoretical Pattern

The Conceptual Model (CM) outlines the logical relationships between several important ideas. It gives context and inspiration for the architectural features covered in the architectural viewpoints, in addition to the generic qualities. The concepts of and connections between the entities in IoT systems are described using a common framework and set of definitions provided by CM. It strives to be broad, abstract, and easy to understand. To accomplish this, it is crucial to define the essential concepts of IoT systems by posing the following queries.

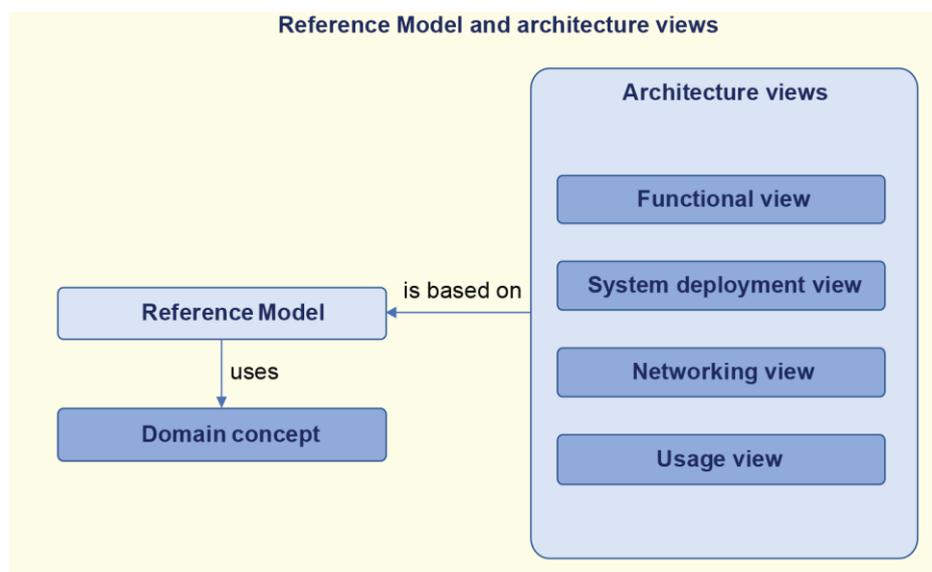


Figure 25. - RM and architecture views (Franberg, 2019)

Figure 25 illustrates how the Architecture Views define the Reference Model (RM), but this relationship also exists in reverse, with the Architecture Views being predicated on the RM. The functional, system deployment, networking, and usage perspectives make up the architecture views.

On the other hand, the RM is defined using the idea of a domain. In an IoT system, a domain is a substantial functional grouping that includes or excludes all the system's entities. Each entity in the system is associated with one or more domains.

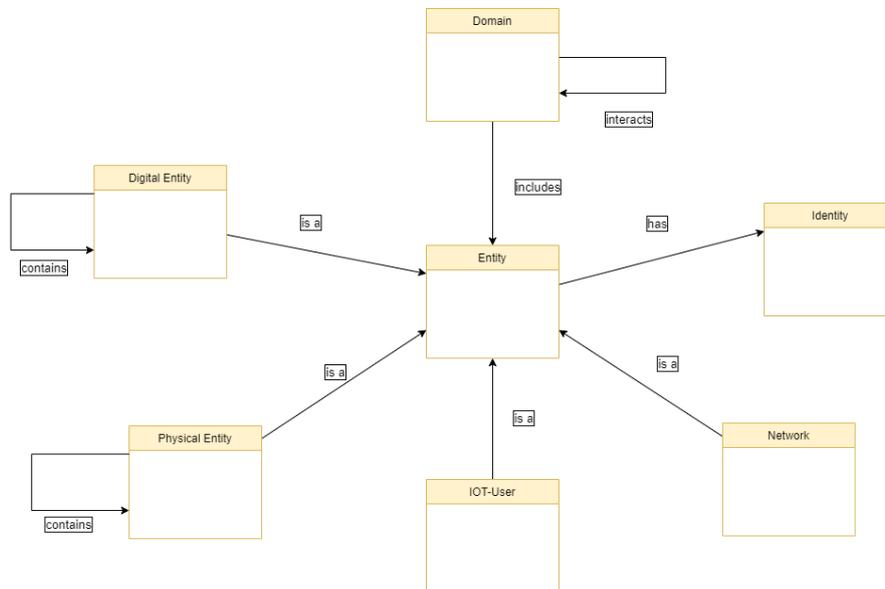


Figure 26. - Entity and domain concepts of the CM. based on source: ISO/IEC 30141:2018

The ideas of entities and domains inside the CM are illustrated in Figure 26. A person, organisation, tool, system, or collection of objects are examples of unique and independent entities that fall under the definition of an entity. An IoT system's components are all regarded as entities. Four fundamental things—physical entities (the item), IoT users, digital entities (IT systems), and communication networks—are identified to clarify the understanding of IoT entities and their relationships.

Principal Characteristics

The IoT RA is described in the following four RA viewpoints:

- IoT RA functional.** The functional perspective is a view of the functional parts required to create an IoT system that is independent of technology. It covers both internal and external functions and illustrates how the supporting activities listed in the usage view are connected and organised. One or more basic system components can be integrated to form a functioning system, and they each perform one or more functional components.
- IoT RA system deployment.** The device, subsystem, and network building elements that make up an IoT system are described from the system deployment perspective. The system deployment view, in contrast, explains an IoT system based on the components that were employed in its implementation, but the functional view represents it based on its functional components.
- IoT RA networking.** The primary communication networks utilized by IoT systems and the entities they connect with are described in the IoT RA networking view. These interconnected networks maintain connectivity between networks and offer communication connectivity,

including data links. The networks are essential for facilitating interactions, communication, and data exchange between entities, domains, and IoT systems. IoT systems also need inter-domain communication networks such as B2B networks, local area networks, the Internet, intranets, enterprise backbone networks, and vast area networks.

- **IoT RA usage.** The used view focuses on the user's perspective on how the IoT system is built, examined, run, and utilized, whereas the functional view emphasizes the necessary functions and connections of the IoT system. This view includes activities, roles and sub-roles, products and aspects that cross various domains.

Potential Interests in AGILEHAND Project

The IoT RA functions might be based on a variety of IoT system properties. The characteristics of the AGILEHAND project that have the most intriguing potential are:

- Increase a device's **usability**, which is reliant on its dependability and network connectivity. Data accessibility is determined by the system's capacity to convey data with a specific level of service.
- Data and software **integrity** are crucial for Internet of Things (IoT) systems to prevent any unauthorized tampering that could jeopardize the system's decision-making processes, whether brought on by broken devices, nefarious people, or environmental factors.
- System creation is made possible by **modularity**, which enables the integration of components in different configurations. Implementers have flexibility in the design of components and IoT systems since they concentrate on standardized interfaces rather than defining each component's internal operations.
- IoT systems depend on the capability of structured information unit exchange based on various but **compatible network** types. Devices communicate with software services that may be close by or far away while transmitting and receiving data. Gateways can be used to link several types of networks, typically between proximity networks and wide-area networks.

3.4. Intelligent Manufacturing System Architecture (IMSA)

A framework for designing and implementing intelligent manufacturing systems is called the Intelligent Manufacturing System Architecture (IMSA). The production resources, information systems, and control systems are only a few of the components that are shown in a high-level picture of an intelligent manufacturing system along with how they interact.

In order to achieve the best performance and efficiency possible during the manufacturing process, the IMSA framework also provides rules for integrating and coordinating these various components. In order to achieve smart manufacturing, it also incorporates the use of AI, IoT, and other cutting-edge technology. Improving the adaptability, intelligence, and flexibility of industrial systems is the primary objective of IMSA.

Background

IMSA is a concept that integrates manufacturing tasks with IT-based tasks to improve the intelligence of both the production process and the final product.

The process of transforming an industrial facility or plant from a draught into an actual entity till its demise is included in the dimension of the product lifecycle, which also covers activities like design, production, logistics, sales, and service. The factory's system hierarchy, which includes layers like equipment, control, workshop, enterprise, and cooperation, is based on the IEC 62264 manufacturing pyramids.

End-to-end integration is reflected in the lifespan dimension, vertical integration is reflected in the system hierarchy's first four levels, and horizontal integration is reflected in the system hierarchy's cooperation level. A dimension that represents IT-based functions is added as the Z-axis of the IMSA once the lifecycle dimension and the system hierarchy dimension are set up as the fundamental plane of manufacturing.

Resources elements, system integration, interconnection, information fusion, and new business patterns are the five layers that make up intelligent functions. The role of each layer is demonstrated using data as an example. Data is produced by the resources elements layer, collected by the system integration layer, sent by the interconnection layer, stored, and analyzed by the information fusion layer, and applied by the new business pattern layer in a variety of ways.

Principal Characteristics

Lifecycle, system hierarchy, and intelligent functions make up the three key components of the Intelligent Manufacturing System Architecture (IMSA), (Figure 27).

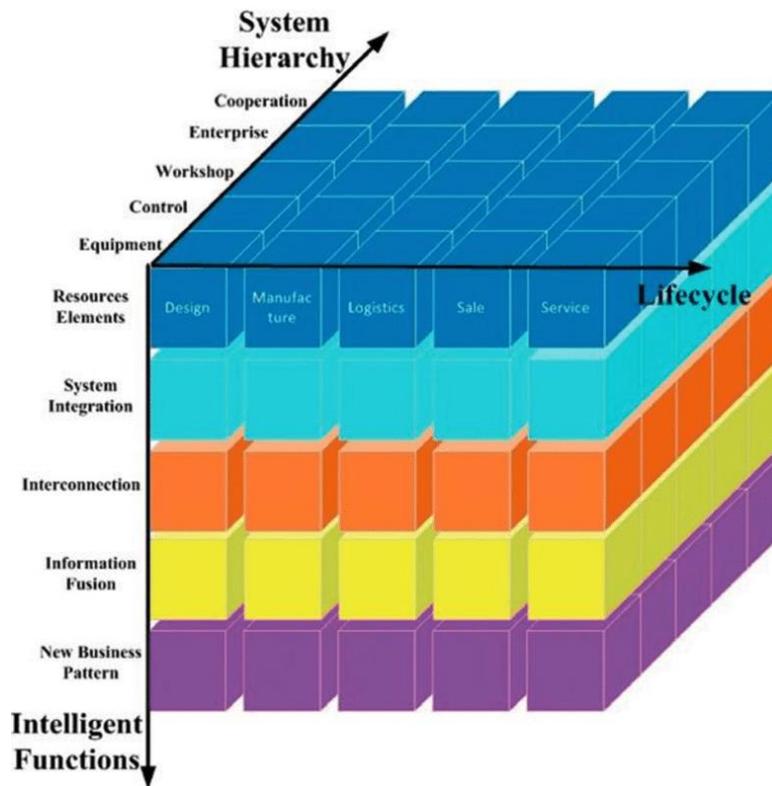


Figure 27. - Intelligent Manufacturing System Architecture IMSA (Song & Jiang, 2020)

- The value-creating activities that make up the **lifecycle dimension** include design, manufacture, logistics, sales, and customer service. These actions are connected and may have an impact on one another. Depending on the sector, the lifecycle's precise stages can change. Research and development, simulation, verification, optimisation, and other processes that are carried out in accordance with business requirements and technological constraints are all included in the **design process**. **Manufacturing** is the process of making products using human labour. Transporting items to their final locations is the subject of **logistics**. The transfer of goods from an enterprise to its clients is referred to as a **sale**. In addition to acts like recycling, **service** also encompasses a variety of behaviours that follow communications between service providers and clients.
- The equipment level is at the bottom of the **system hierarchy dimension's** layered structure, which is then followed by the control level, workshop level, enterprise level, and cooperation level at the top. The network structure has been flattened, and the system hierarchy integrates intelligence and internet protocols. Sensors are part of the **equipment level**, which provides the technological framework for manufacturing processes. PLCs, SCADA systems, distributive control systems (DCS), and field bus control systems are all part of the control level (FCS). The **workshop level** incorporates MES systems and focuses mostly on factory/workshop production management. ERP, PLM, SCM, and CRM are all part of the enterprise level, which focuses on **enterprise** operation management. With the sharing of information over the internet between various businesses in the industrial chain, the **cooperation** level enables coordinated R&D, intelligent production, precise logistics, and intelligent service.
- Manufacturing processes have been improved with a variety of intelligent capabilities, such as self-sensing, self-learning, self-decision making, self-execution, and self-adaptation, using the

most recent information and communication technology. The fusion of information, interconnection and collaboration, resource integration, system integration, and new business models are a few examples of these cognitive functions. **Resources elements** describe the digital method by which the company uses tools or resources during the production process. The **integration** of intelligent machinery into intelligent production units, lines, digital workshops, factories, and even intelligent manufacturing systems by the organisation is referred to as system integration. Equipment, systems, and businesses are connected by wired, wireless, and other communication technologies through **interconnection** and interworking. **Information fusion** is the term used to describe the cooperative exchange of information using big data, cloud computing, and other modern information technologies. In order to protect the privacy of the information, communication technology that is based on interconnection and cooperation is also used. The term "**new business pattern**" describes how an organisation integrates the value chain amongst other businesses to create new industry configurations.

Potential Interests in AGILEHAND Project

Information Management System Architecture (IMSA) offers an organised method for managing the many components of an information management system, making it a useful tool for AGILEHAND. IMSA might be particularly interested in AGILEHAND in the following areas:

- Planning: The project's goals, objectives, and needs can be clearly identified with the aid of IMSA, which also offers a framework for deciding the project's scope and direction.
- Investigation: With the use of IMSA, it is possible to assess the current systems and procedures, spot any gaps or weaknesses, and figure out how to meet the demands indicated during the planning stage.
- Concept: To guarantee that the project is clearly defined and that the system is developed in a way that fulfils the needs of the company, IMSA can be used to generate a complete project plan that includes specifications for hardware, software, and interfaces.
- Development: IMSA offers a framework for verifying that the system is installed and configured appropriately and can be used to direct the development and testing of the system.
- Operation: The system's continuing management, including monitoring, troubleshooting, and maintenance, can be assisted by IMSA.

Therefore, IMSA can be helpful in offering a thorough and structured approach to managing an information management system's complete lifespan, which can help to assure the success of AGILEHAND by giving the project team a clear framework to follow.

3.5. Non-Destructive Kit for Industry 4.0 Evaluation (NIKI 4.0)

in December 2017, the research collaborators Hahn-Schickard, the FZI Research Centre for Computer Science, and the University of Applied Sciences Offenburg released an open-source prototype for the NIKI 4.0 project. Small and medium-sized firms now could test an Industry 4.0 environment and assess the potential advantages of moving to relevant manufacturing. The

concepts of Industry 4.0, especially in smaller enterprises, are met with scepticism, especially as adoption often requires large investments. The German Federal Ministry of Economics actively promotes entrepreneurial tests like those made possible within the framework of the NIKI 4.0 project and also offers information and guidance on technological change in conjunction with other research organisations like the Fraunhofer Institute for Production Technology and Automation IPA (*Industrie 4.0: Open-Source Project Promises Industry 4.0 Trials without Risk*, 2018).

Background

The "Non-Destructive Kit for Industry 4.0 Evaluation" project, also known as "NIKI 4.0," aims to develop a kit for small and medium-sized enterprises (SMEs) that will enable existing production facilities to be quickly and affordably expanded using non-destructive ad-hoc sensor technology and information couplers. The unique characteristic is that production equipment and machinery stay the same, and the addition of new data does not immediately disrupt production operations. Along with the communication gateway, which is also a part of the NIKI 4.0 kit, and the visualisation of collected data based on augmented reality, 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. NIKI 4.0 also offers a framework for specialised extensions and adaptations as an open-source platform. Because of this, NIKI 4.0 may be used to construct new Industry 4.0 evaluation and migration kits as well as whole new business models that utilise the NIKI 4.0 kit.

Principal Characteristics

Figure 28 illustrates the toolkit's typical three-tier architecture. To collect data from sensors that can be attached to existing industrial machinery without causing it to cease functioning, the data acquisition layer has properties. It can be used to gather data from Fieldbus sniffers (like Profibus/Modbus/Interbud sniffers) that can be connected to already-existing field buses or ad hoc sensors (like power/environment/ambient sensors, sensors for monitoring energy flows). The communication and aggregation layer is represented by the NIKI 4.0 gateway, which links the business systems and the sensor nodes. It oversees using WSN to wirelessly collect data from the sensor nodes (Wireless Sensor Network). Ethernet and Wireless Local Area Network (WLAN) are potential other strategies, though. In the gateway, the data are first reviewed before being further pre-processed. The data are transformed into OPC Unified Architecture (OPC UA) compliant data models and stored in a database engine enabling historical data access during the pre-processing stage. As a result, the sensor's current value, historical information, and historical events are accessible to OPC UA clients. The visualization layer, which presents the acquired data in a way that enables the user to discover potential improvements and optimizations that may be achieved using Industry 4.0, offers a user-friendly interface.

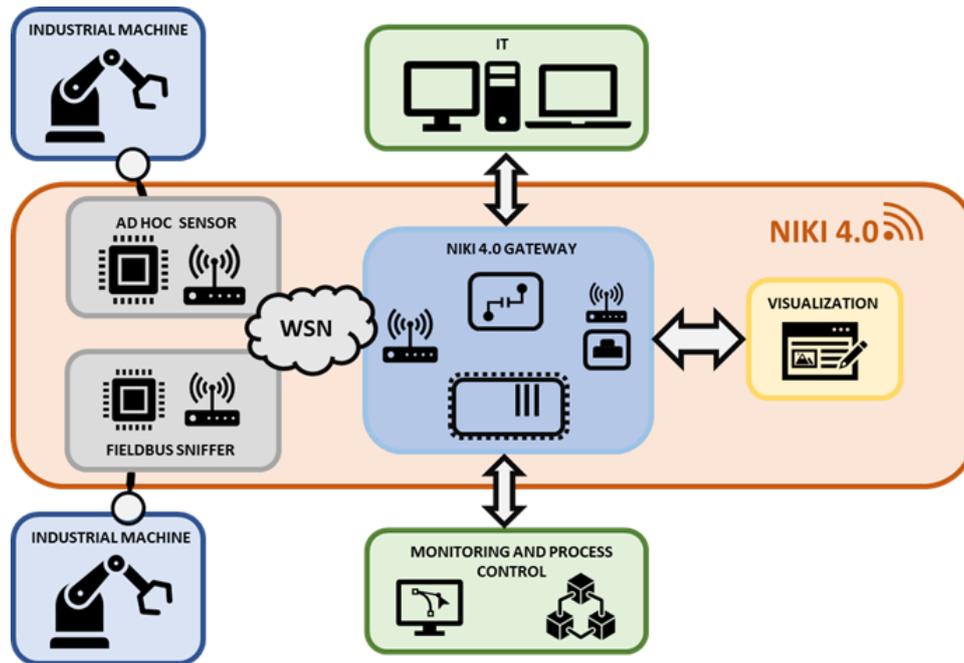


Figure 28. – NIKI 4.0 Architecture

The Fieldbus sniffer's main objective was to enable SME personnel to connect to existing networks without the need for PLCs (Mamo et al., 2017). The sniffer was built using the Profibus technology, which is frequently used in modern manufacturing plants. One of the most often used media in the Profibus network is RS485. The RS485 diagnosis interface offered by Profibus slave devices enables devices to connect for network-wide data collection and monitoring as well as diagnosis. This comprises data related to diagnosis, I/O, processes, load registers, and data related to context and functions invocation. The only data that is filtered out of this is diagnosis, alert, status, and I/O data to extract the Profibus-type packets with constant and variable length data. Before being sent via the WSN to the NIKI4.0 gateway, the protocol data units (PDUs) of the filtered packets are modelled with the IP Smart Object (IPSO) data model. The General Station Data (GSD) cover the communication characteristics and provide information on the fundamental features of Profibus devices; however, they do not cover device parameters. Generic data models, such as IPSO and EDDL data models, were chosen over GSDs because they can be easily transformed into high-level OPC UA data models and are supported by most fieldbus protocols. The gateway incorporates each device therefore and establishes a unique description file for each device.

A sensor to measure electrical energy consumption (E-Meter), an environment information sensor (EIS), and a sensor based on the linear variable differential transformer (LVDT) principle are all included in the NIKI4.0 Toolkit. These sensors – are simple to install in manufacturing operations with no or minimal downtime. They are all built on a single sensor node standard architecture, making it simple to add more sensor nodes to the NIKI4.0 toolset.

The NIKI4.0 toolkit's gateway and sensor nodes are in constant contact with one another. This makes it possible for the nodes to be configured and for the right data to be delivered. The Lightweight M2M (LWM2M) protocol is the cornerstone of all sensor communication, starting at the top. LWM2M offers a method for the gateway to watch the pertinent IoT sensor nodes, negating the need to employ Message Queue Telemetry Transport (MQTT).

The Constraint Application Protocol (CoAP), which serves as the foundation for LWM2M, employs the IP protocol as the transport mechanism. This enables us to link many types of sensors using various communication technologies. With 6LoWPAN technology, which enables IPv6 communication on devices with limited resources via WSN IEEE802.15.4, it is possible to link small, low-power sensor nodes. If greater bandwidth is needed, sensors can also be connected utilizing Ethernet or WLAN technologies. These technologies can be effortlessly integrated because of Internet Protocol (IP)-based communication.

The NIKI4.0 gateway is a crucial element of the NIKI4.0 Toolkit. Using the WSN, it gathers data from sensor nodes, analyses it, and then delivers it to the visualization layer. The data can be utilized to make well-informed decisions at the visualization level, including forecasting the future, streamlining processes, and maintaining manufacturing facilities with predictive maintenance. The Beagle Bone Black (BBB), which serves as the gateway's primary processor and runs Linux, is housed on a baseboard that also houses a communication module (based on Texas Instruments). Data from the sensors are gathered by the communication module, which sends it to the BBB for processing.

The main software embedded in the BBB includes open-source server-side implementations of OPC UA technology and the Wakaama LWM2M protocol. The OPC UA server provides extensive information capabilities for modelling simple and complex field devices, while the LWM2M protocol provides device management capabilities such as the discovery of new field devices. To keep IoT devices and the IoT gateway synchronised, the LWM2M protocol defines several interfaces that allow IoT sensors (i.e., LWM2M clients) and the IoT gateway (LWM2M server) to exchange messages. For example, the IoT sensor uses the logging interface to inform the gateway that it is awake and starts listening to queued operations. The gateway further models the data transmitted by the IoT device and stores it along with a timestamp. Data filtering, data modelling (using the OPC UA information model), and data storage are the gateway's primary functions, (Nsiah et al., 2018).

Potential Interests in AGILEHAND Project

An open-source toolkit called NIKI 4.0 is accessible on GitHub (<https://about.gitlab.com/>). Although there are currently no standards for it, interest in this tool is rising. The NIKI 4.0 ('Non-Destructive Kit for Industry 4.0 Evaluation') toolbox specifically enables retrofitting older machines to bring them closer to the industry 4.0 paradigm without having to halt the machine itself or modify/destroy its structure. With its three-level structure and use of well-known protocols (such as OPC UA), NIKI 4.0 is comparable to previous systems (e.g., RAMI 4.0). The toolkit may be used in the framework of the AGILEHAND project for any applications wishing to update outdated machinery, increase their connectivity, or include IIoT technologies. This design offers a solid foundation for integrating new technologies into legacy systems, particularly in the field of smart retrofit.

3.6. MTConnect

An open-source standard for data transmission and communication across manufacturing tools and equipment is called MTConnect. Organizations can gather, analyze, and use data from their manufacturing operations thanks to this uniform method of obtaining data from various machines and gadgets (*MTConnect*® *Standard Part 1.0-Fundamentals Version 2.1.0*, 2023). By offering real-time monitoring of manufacturing devices, MTConnect enables businesses to increase operational efficiency, cut costs, and boost competitiveness in the global market. Because this data is uniform and free of any proprietary formats, developers and integrators may concentrate on creating useful applications rather than worrying about how to translate this data. Production machinery, sensor packages, and other gear may be used as data sources.

Background

As it was already indicated, MTConnect aims to offer a uniform method of obtaining data from various equipment and gadgets. The following elements make up the MTConnect reference architecture (*Standard Part 2.0-Devices Information Model*, 2021), see the Figure 31.

- **Equipment:** This refers to any tangible property utilized to outfit a manufacturing facility's operations. They could include equipment like workstations, ovens, sensor units, and software programmes.
- **Agents:** These are computer programmes that run on industrial equipment and gather data from it. To make the device-specific data retrievable, the agents convert it into the MTConnect standard format.
- **Adapters:** These are parts that convert data from the MTConnect standard format into a format that other systems, including enterprise resource planning (ERP) or factory execution systems, may use (MES).
- **MTConnect Standard:** This is a collection of data models and XML schemas that specify the type and organization of the data that can be shared via MTConnect. Definitions for alarms, equipment status, and other significant manufacturing data are included.
- **MTConnect Server:** This part oversees gathering information from agents and making it accessible to other systems. The server serves as the main storage location for MTConnect data and offers a consistent method of data access from various devices.
- **MTConnect Client:** Other systems utilise this component to access data stored on the MTConnect Server. Data may be retrieved and used easily by integrating the client into existing systems like ERP or MES.

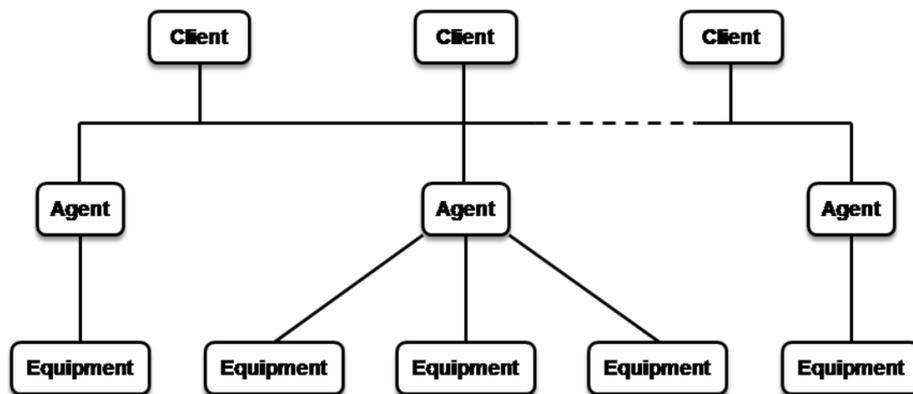


Figure 29. – Concept of MTConnect Implementation

Principal Characteristics

MTConnect, an open-source communication standard, has some fantastic features (*Standard Part 2.0-Devices Information Model, 2021*). The key attributes of MTConnect are as follows:

- **Data Gathering:** MTConnect offers a standardised method for gathering data from industrial equipment like CNC machines, robots, and sensors. The information gathered by MTConnect agents is converted into a common format to facilitate access and analysis.
- **Interoperability:** MTConnect offers a universal language for device communication regardless of the maker or model. This makes it possible for businesses to combine data from many devices and use it to enhance their processes.
- **Flexibility:** Because MTConnect is scalable and adaptable by design, it may be used in a variety of production contexts. The requirement is made to be readily adaptable to new technologies and modifications in the industrial environment.
- **Open-Source:** As an open-source standard, MTConnect is accessible to organisations at no cost. This enables businesses to take use of the MTConnect community's combined knowledge and contribute to its growth.
- **Data Security:** MTConnect offers a safe means of transferring data across gadgets. Sensitive manufacturing data is secured by the standard's provisions for secure data transfer and access control.
- **Real-Time Monitoring:** MTConnect offers real-time monitoring of manufacturing equipment, allowing businesses to identify issues as they arise and take swift corrective action. Real-time decision-making and control systems can use the data gathered by MTConnect because of its real-time nature.

Potential Interests in AGILEHAND Project

MTConnect offers a standardised method of gaining access to and gathering data from manufacturing devices, which can then be used for AI and ML applications.

The massive volumes of data that MTConnect agents gather from connected devices can be fed into AI and ML algorithms. Machine learning models may be trained using this data, which also offers useful insights into manufacturing processes. The information can be used, for instance, to spot patterns and trends in the manufacturing process, anticipate equipment breakdowns, or improve production schedules.

The MTConnect reference architecture can also incorporate AI and ML utilising AI-powered adapters. The data gathered by MTConnect agents can be analysed by these adapters using machine learning algorithms, giving real-time insights into the production process.

In conclusion, MTConnect offers a standardised method of obtaining data from manufacturing devices and transferring it to a computer so that it may be entered into AI and ML algorithms. The MTConnect reference architecture's use of AI and ML can offer useful insights into manufacturing operations, enhancing operational effectiveness and decision-making.

3.7. GAIA-X

An infrastructure and data ecosystem called GAIA-X was created to adhere to European requirements (Federal Ministry of Education and Research, 2019). GAIA-X promotes user-friendly, dependable, and cutting-edge data interchange and services by relying on well-established standards, open technologies, and concepts. Additionally, it seeks to promote participant connectivity and interoperability for both data and services, (Reinhardt et al., 2020).

Background

To support uniform access to GAIA-X, authenticate engagements, and allow Providers and Consumers to communicate, the GAIA-X architecture integrates technological techniques including federation, self-descriptions, and policies, as well as identification and trust. GAIA-X is in line with the European Data Strategy (European Commission, 2020), which aims to establish a unified market for data while giving enterprises safe and convenient access to high-quality industrial data. The goal is to create and put into place an EU federation of cloud infrastructure and data services, as well as a data-sharing architecture and governance system.

The GAIA-X architecture's basic beliefs and vision are reflected in the architecture's guiding principles (Figure 30). These include Federated Systems, which defines a set of standards, frameworks, and legal guidelines for autonomous providers; Openness and Transparency, which encourages open-source licences and welcomes contributions; Interoperability; and Authenticity and Trust, which calls for an identity management system for secure interactions without relying on a single business or government's authority.

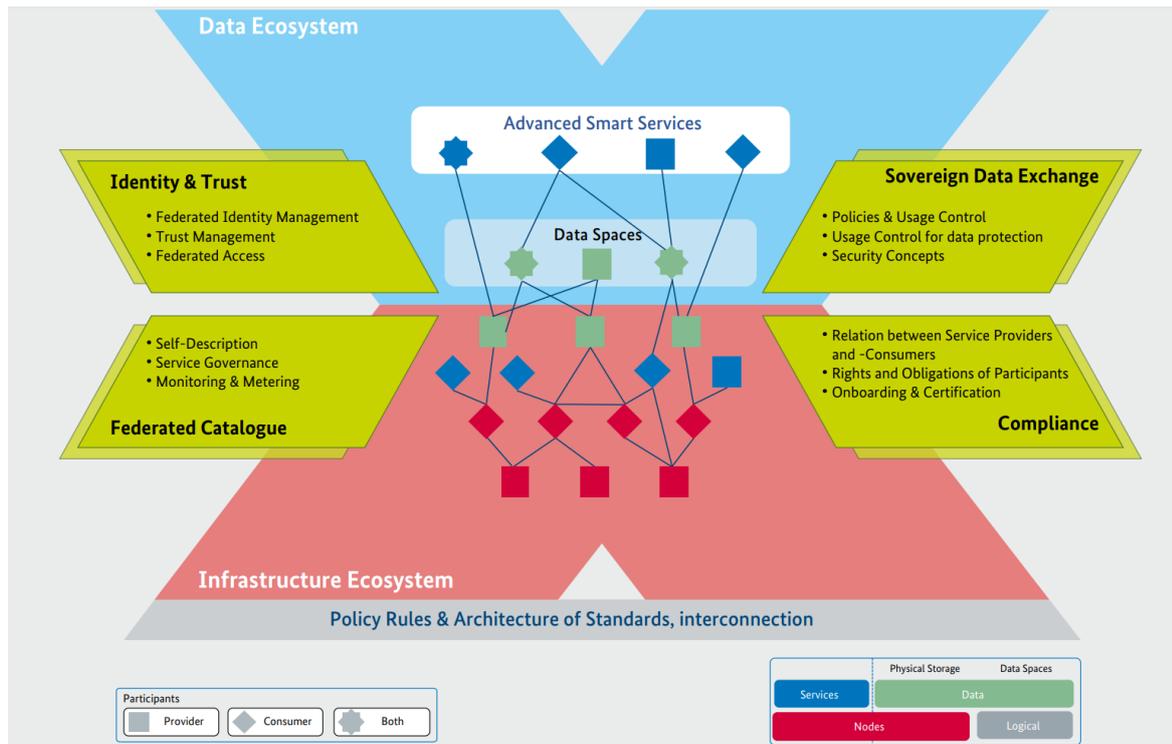


Figure 30. – Concept of GAIA-X Architecture

Principal Characteristics

The Data Ecosystem and the Infrastructure Ecosystem are the two ecosystems that make up the GAIA-X ecosystem. The Data Ecosystem is focused on Data Spaces and Advanced Smart Services, whereas the Infrastructure Ecosystem is focused on providing or consuming infrastructure services through the Asset known as a Node. Participants in the ecosystem are divided into Providers and Consumers in accordance with the European Data Strategy. Services serve as the connecting link between Providers and Consumers, connecting Nodes and Data. Although it orchestrates the ecosystem and offers technical ideas, federation and interoperability functionality, GAIA-X is not involved in specific transactions between Participants. Four domains are used to organize the federation services, which comprise organizational support and infrastructure services.

The GAIA-X architecture addresses the ideas of **identity and trust** at many levels.

The ecosystem's offerings from Providers are stored in the **Federated Catalogue (Interoperability)**. The important architectural components and their interrelationships, such as self-description, service governance, and monitoring and metering, are covered in the second half of the catalogue.

Using control mechanisms and a thorough security concept, the GAIA-X ecosystem's **data exchange** is guaranteed to be sovereign. Standards for data interchange interoperability will also be developed. Policies and Use Control, Usage Control for Data Protection, and Security Concepts all involve the following concepts.

Within the GAIA-X ecosystem, effective **security and data protection** depends on more than just technical solutions. Aspects of organization and governance are also crucial. The Connection

between Service Providers and Consumers, Participants' Rights and Obligations, or Onboarding and Certification are some of the essential components.

Potential Interests in AGILEHAND Project

An interoperable reference architecture is offered by GAIA-X. With a focus on tying together all players in Europe, it encourages standard-setting, open technologies and ideas of simple, innovative, high-quality data exchange and services. The future use of the solutions in other businesses that accept the same interoperability principles would benefit from the adaptation of this data ecosystem to the AGILEHAND Project.

3.8. Reference Architecture for Smart Device

Background

Digital services known as "smart services" employ data from physical objects to generate value for users, such as automatic consumables replenishment. Smart services are made possible by new technical system capabilities and are necessary for evolving business models like pay-per-use. The planning of new services based on an existing manufacturing company product is supported by the reference architecture, which takes into account both of these factors.

The concept of the Business Model Canvas, which exposes a complicated problem in a clear and descriptive manner to encourage innovation in subsequent development, forms the foundation of the suggested reference architecture (Rabe et al., 2018). An overview of the reference architecture is shown in Figure 31, which includes components for both the market and technological perspectives to enable the integrated design of new market offerings.

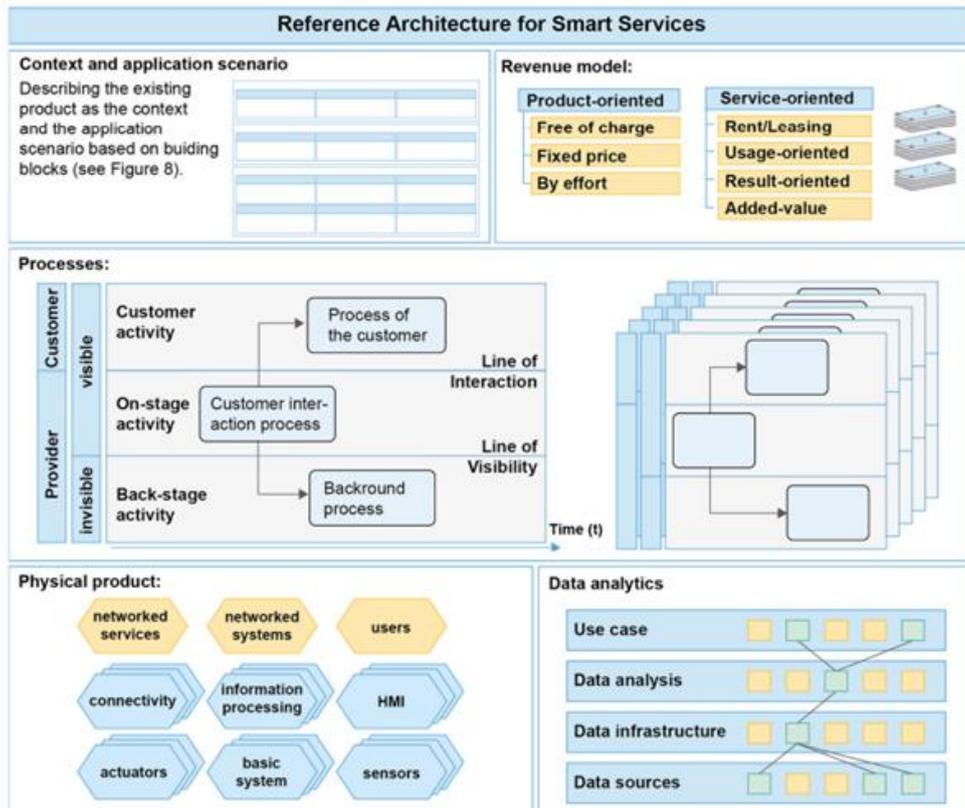


Figure 31. - Reference architecture for Smart Devices

Principal Characteristics

By using building blocks, the context and the application situation may be established. Recurring building blocks were developed through the empirical investigation and already-existing methodologies in literature, from which application scenarios can be deduced. The defined building elements are arranged in the Figure 32 according to their complexity and level of generated value. Since it is one of the key constraints and its architecture should typically not be changed much, the existing product is referred to as the context. To find opportunities for new services, it is also crucial to describe the frequent circumstances of product users.

visualization		
consulting Advice before and during the use phase regarding product and process.	instruction and training Instructions and training for the construction, use and dismantling of the product.	self-service Interactive instructions for maintenance and repair of the product.
monitoring and instructions		
monitoring Preparation of data concerning the product based on sensors and external sources.	note and warning Notes and warnings based on predefined rules and data regarding the product.	service support Preparation of maintenance/repair by means of preliminary reports
assistance		
updates and upgrades Transfer of updates and upgrades to improve and extend the product.	planning support Suggestions for time and resource planning.	remote access Access to the product or its control by other systems.
prediction Prediction of future probable conditions and errors.	automated ordering Automated ordering of consumables and spare parts.	automated optimization Automated implementation of optimization measures in the process.

Figure 32. - Building blocks of the architecture of Smart Devices.

The main components of the architecture are succinctly explained here:

- Revenue model:** Given the dependence on technical implementation, the revenue model is essential. Revenue models may be beneficial or even required, depending on the application situation chosen. If a revenue model is chosen first, then helpful or necessary application scenarios emerge that must be put into practice.
- Processes:** The customer contact idea is represented by the service processes. It is possible to present processes using a variety of methods, with the service blueprinting method emphasizing client contact (Bitner et al., 2008). The user's participation is crucial since they can offer valuable information on which services are built. Standard procedures that can also be utilized as building blocks are defined for each building block.
- Physical product:** A Cyber-Physical system includes smart services. A comparable architecture can therefore be applied to the representation. The CPS is a source of information regarding both the state of the environment and its own. Here, the emphasis is on the use of sensors and networking with users and systems in the environment to collect data. The transmission of collected data to IT platforms (clouds) enables centralized data networking and processing. Thereafter, the deployment of digital services is carried out once more based on the user's human-machine interface (HMI).
- Data analytics:** Every service that uses data analytics is "smart" since it incorporates intelligence into it. The Kuehn et al. (2018) Analytics Canvas, a semi-formal specification technique for expressing analytics use cases, the required infrastructure, as well as requirements for each domain, is used to create data analytics applications. The strategy is built on four stages, starting with problem comprehension and domain analysis before moving on to analytics use cases. The data must next be analyzed to identify the data sources, such as sensors or file systems. Choosing where to store the data is the third stage (data pools). The final step is to specify what should be done with the data, such as making predictions about the future, resolving issues, or automating routine tasks like ordering supplies.

Potential Interests in AGILEHAND Project

Any planning for a smart service, such as one that can support AGILEHAND AI solutions, must consider market and technical perspectives because the revenue model, or business model, is vital to creating value for consumers. This reference architecture supports the exploitation of the AGILEHAND-related goods and services from the top-down (market pull) and bottom-up (technology push).

3.9. Line Information System Architecture

Background

A prototype-oriented information model and defined transformation services are features of the event-driven architecture known as LISA. It has a free coupling, is adaptable, and is simple to retrofit legacy equipment. The architecture is being installed at a major automotive manufacturer and has also undergone evaluation using both real-world industrial data and industrial demonstrators, (Theorin et al., 2015).

Principal Characteristics

A component called an Enterprise Service Bus (ESB), which manages message routing across dispersed applications, is used by LISA. The following Enterprise Integration Patterns (EIPs) should be supported by the ESB to prevent PtP connections and guarantee loose coupling, (Figure 33):

- **Message:** The data or information is condensed into a message that may be sent across a message bus.
- **Messaging:** Using programmable forms, messages are sent instantly, frequently, reliably, and asynchronously. A new message is sent to the message bus whenever an event occurs in the messaging system.
- **Publish-subscribe channel:** Each channel subscriber receives a copy of every message transmitted on a publish-subscribe channel.
- **Message filter:** An incoming message is deleted if its content does not meet the criteria set forth by the message filter. Each application can further filter incoming messages thanks to this pattern.

Any ESB that supports these patterns could take the place of Apache ActiveMQ, which is utilized in the LISA prototype. An overview of LISA's communication architecture is shown in the Figure below.

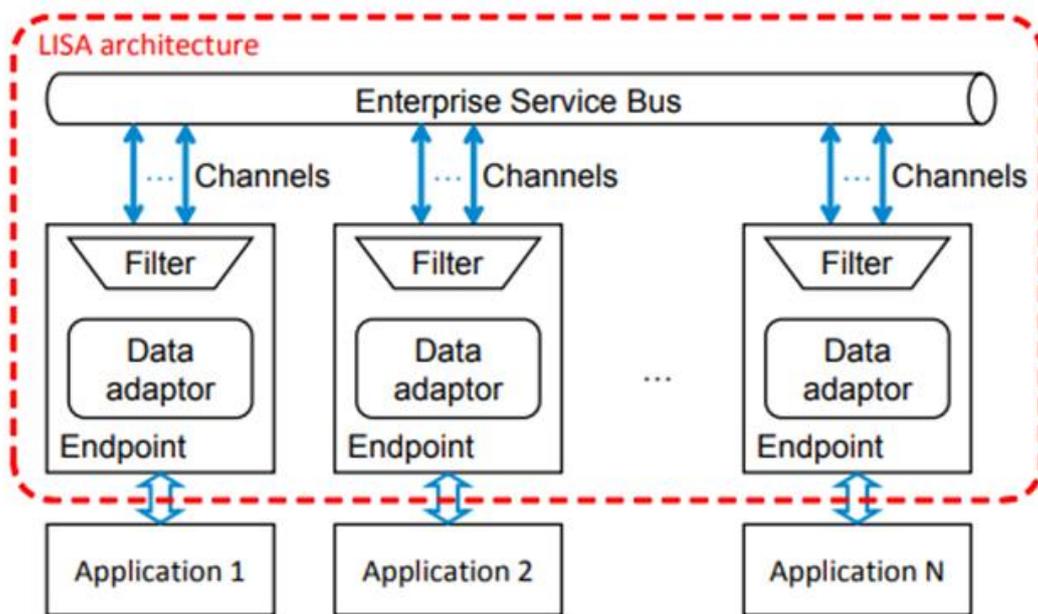


Figure 33. - Background of LISA architecture

Through endpoints, which oversee

- 1) adapting events and information to the LISA message format,
- 2) publishing LISA messages on the corresponding channels on the ESB, and
- 3) filtering incoming LISA messages from the ESB, applications (devices, services, and external applications) are connected to the ESB.

Just the endpoint needs to be altered whenever an application is altered (for instance, because of new measurements, renamed variables, or replacement hardware). There is no need to update any more endpoints or programmes.

The LISA message format was created to be straightforward and to impose the least amount of structure as feasible. There is a header and a body to it. The header includes details about message routing and sending. An ordered attribute-value map makes up the body. Values can also be lists or maps but are typical of rudimentary data types. Thus, hierarchical structures are supported by LISA messages. The event id and timestamp, both in the body, are the only necessary attributes. LISA should be able to integrate any device on levels 1 and 2 even though each plant has a different system structure and different types of devices.

Potential Interests in AGILEHAND Project

LISA is an event-based service-oriented architecture that provides adaptability and scalability for both the management of low-level applications and the gathering of higher-level data. Devices like PLCs, robots, product carriers, and operators transmit and receive low-level events that are then aggregated to provide the needed information that may be gathered for AGILEHAND solutions purposes. With LISA, all communication is event-based at a finer granularity.

4. AGILEHAND Reference Architecture

This section will provide a holistic view of the AGILEHAND Reference Architecture including a reference model from layer and level point of view.

The AGILEHAND reference architecture provides guidance for implementing AGILEHAND SUITES in use cases and, more in general, in the manufacturing sector. The architecture makes it easier for stakeholders, such as device manufacturers, application developers, and consumers, to comprehend how AGILEHAND solutions are implemented. This document specifies a AGILEHAND reference model for manufacturing in terms of layers and levels:

- **Layers:** the AGILEHAND framework for manufacturing is divided into layers that correspond to levels of task performance.
- **Levels** divide each layer into system levels and subsystem levels.

For the purposes of this document, the terms and definitions given in ISO 23247-1 and the following apply.

The following **Errore. L'origine riferimento non è stata trovata.** shows the layers in which A GILEHAND operates. In particular, we can divide the Reference Architecture into four layers:

- manufacturing layer

The visible manufacturing resources' physical, logical, and functional space. The manufacturing layer is made up of the resources that can be seen during production, including workers, tools, materials, processes, facilities, and environments. The device communication layer keeps a close watch on the manufacturing layer.

- device communication layer

The spatial/logical/functional area that uses sensors to gather information from the manufacturing layer and controls and actuates devices in the manufacturing layer. The device communication layer links Manufacturing Levels to their AGILEHAND solutions for synchronization.

- device communication level: (set of) system or device providing device communication

EXAMPLE: a cell controller that sends commands to the machines in a production cell and gathers data from the machines' sensors

- AGILEHAND SUITES layer

AGILEHAND SUITES' functionalities, such as visualization, presentation, synchronization, historical archiving, data analytics, modeling, and optimization, are provided via a spatial/logical/functional area. Applications and services that run on the AGILEHAND SUITES are hosted by it. It uses information provided by the user layer to provision the AGILEHAND solutions at the beginning of a session. Throughout the session, it updates the AGILEHAND SUITES using

data provided by the device communication layer. At the conclusion of a session, it sends the final state of the AGILEHAND solutions to the user layer.

- user layer

It uses the applications and services offered by the AGILEHAND SUITES layer in a spatial, logical, or functional domain. Applications that analyze the AGILEHAND models for people and systems are hosted on the user layer. An application provides data to provision the AGILEHAND solutions at the beginning of a session. An application archives the final values of the AGILEHAND SUITES at the conclusion of a session.

- user level: human users, applications, and systems that use the services provided by the AGILEHAND SUITES level.

EXAMPLE: An ERP system that updates the current status of resources in its database using application programming interfaces (APIs) given by a digital twin application.

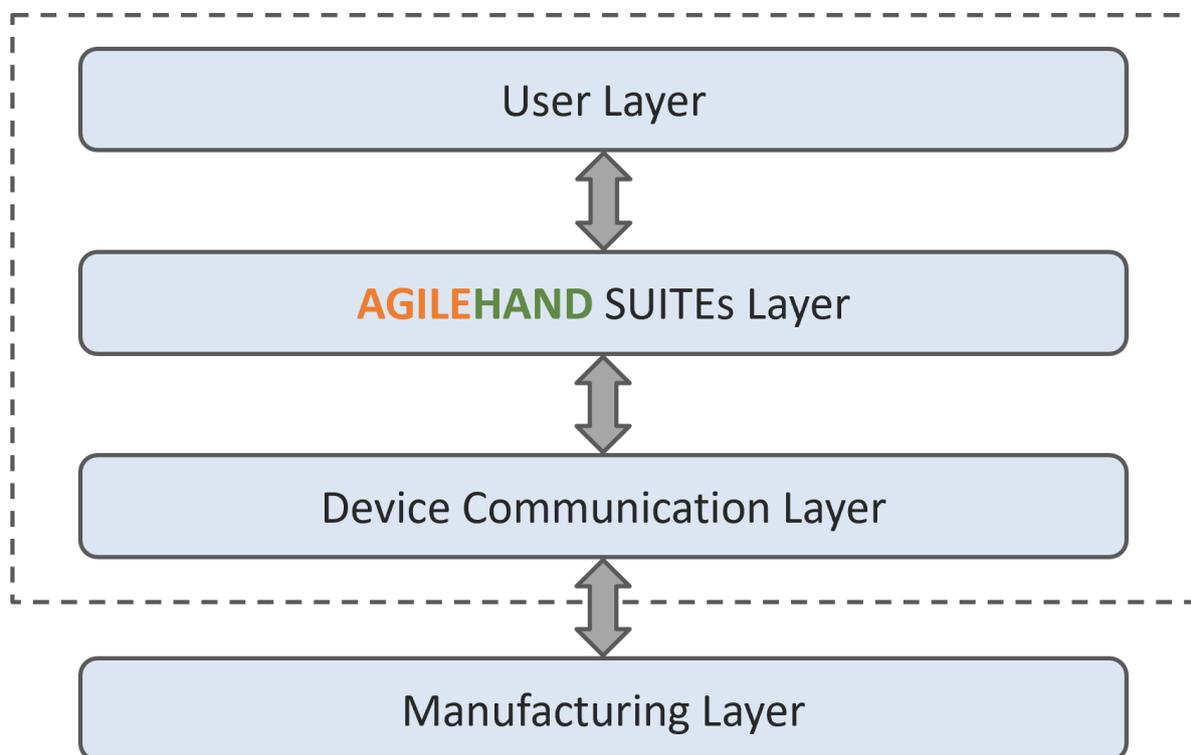


Figure 34. - Layer-based AGILEHAND reference model

4.1. Level-based reference architecture

The level-based reference architecture divides the AGILEHAND framework into systems and sub-systems that manage the layers described in previous section. The Figure 35 describes the level-

based reference architecture. An implementation shall implement these levels or similar levels to create the functionality required for each layer.

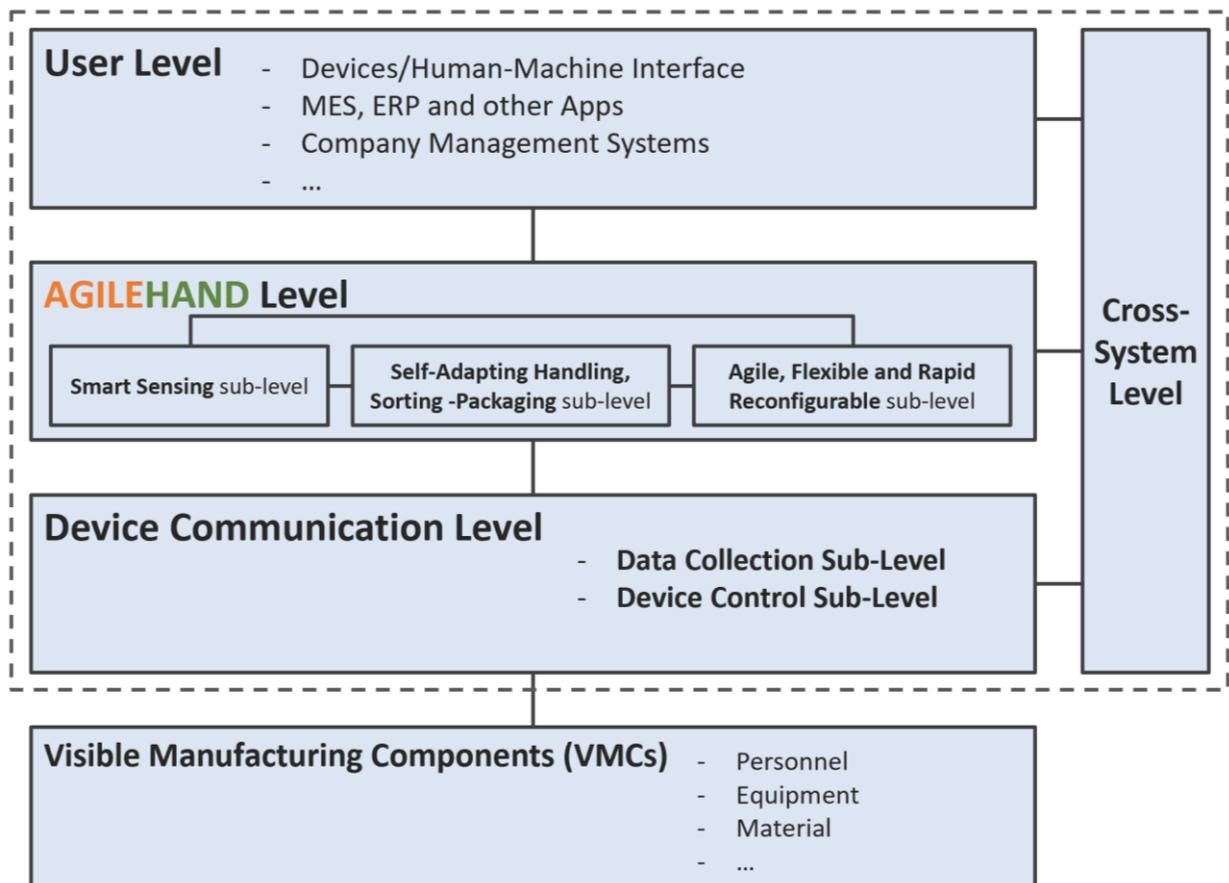


Figure 35. - Level-based AGILEHAND reference architecture

In particular, a description of every Level can be given as follows:

Device Communication Level

A device control sub-level and a data collection sub-level are both part of the device communication level, which is used to communicate with and control visible manufacturing components.

- Data collection sub-level: The data collection sub-level collects data from Visible Manufacturing Components. The AGILEHAND levels use the collected data to synchronize the AGILEHAND solutions with its corresponding Visible Manufacturing Components. The data collection sub-level may include executables in the form of a computer program (agent).
- Device control sub-level: The device control sub-level controls and actuates Visible Manufacturing Components such as handling robots or cutting machines. The device control sub-level may include executables in the form of a computer program (agent).

AGILEHAND level

The AGILEHAND level is made up of three SUITES: Smart Sensing SUITE, Self-Adaptive Handling, Sorting and Packaging SUITE and Agile, Flexible and Rapid Reconfigurable SUITE.

More in detail, these three SUITES consist of different sub-levels that are the AGILEHAND Other Exploitable Results (OERs):

- Smart Sensing sub-levels: AGILEHAND Grade the Quality (GQ^{SENS}), AGILEHAND Self-Calibrating (SC^{SENS}), AGILEHAND Data-Sets (DS^{SENS})
- Self-Adaptive Handling, Sorting and Packaging sub-levels: AGILEHAND Self-Adaptable Transportation systems (ST^{HAND}), AGILEHAND Collaborative Robot (CR^{HAND}), AGILEHAND Robot-Robot (RR^{HAND})
- Agile, Flexible and Rapid Reconfigurable sub-levels: AGILEHAND Product-Oriented Traceability (PT^{AGILE}), AGILEHAND Data-Driven Digital Twin (DT^{AGILE}), AGILEHAND Production Reconfiguration (PR^{AGILE}), AGILEHAND Production Execution Optimization Toolkit (PE^{AGILE}).

User level

The user level hosts the applications of the framework.

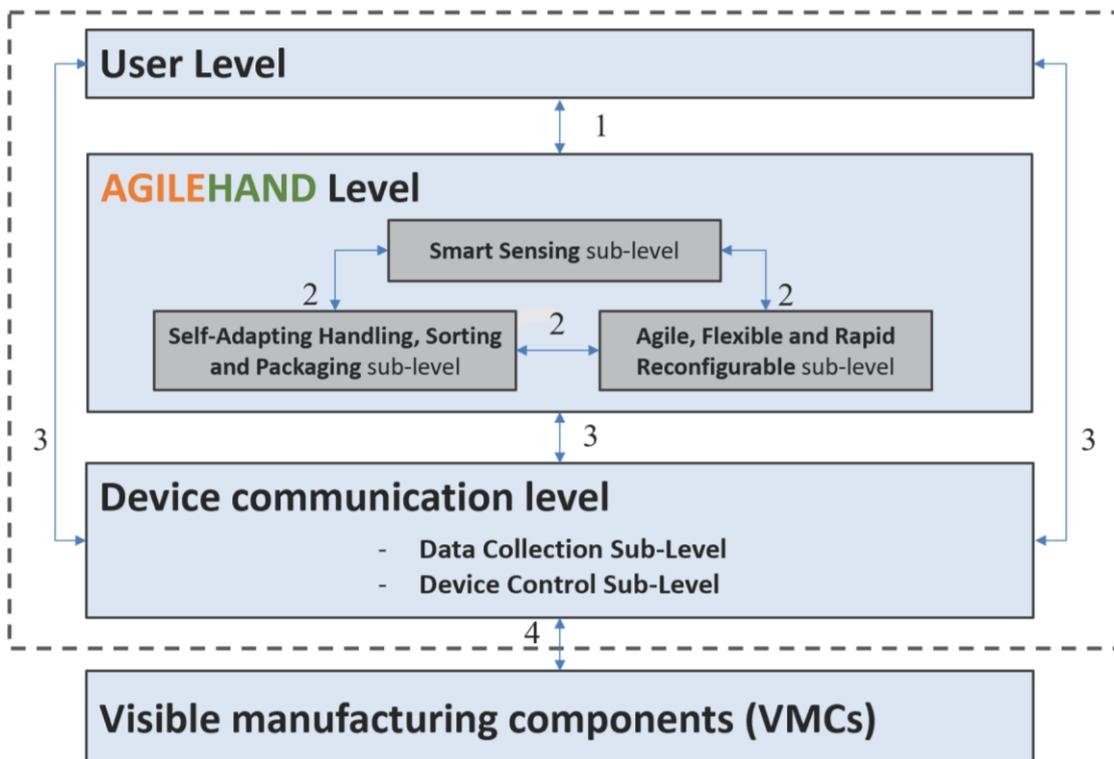
Cross-system level

In order to provide common features like data translation, data assurance, and security support, the cross-system level spans layers.

4.2. Networking view of reference architecture

This section defines a networking view. The networking view shall apply to the AGILEHAND reference architecture. Figure 36 describes the four types of communication networks that are used to connect the AGILEHAND levels.

In particular, a description of every network can be given as follows:



Network meaning

1- user network; 2 - service network; 3 - access network; 4 - proximity network

Figure 36. - Networking view of AGILEHAND reference architecture

User network

The user level and the AGILEHAND level are connected by the user network. The user level utilizes the AGILEHAND solutions over this network. The user network may be a private intranet or the public Internet.

Service network

The operation and management sub-level, application and service sub-level, and resource access and interchange sub-level are all connected through the service network. Typically, the service network is a wired network that uses IP-based protocols. A service network is not required if the AGILEHAND level is implemented as a single private system.

Access network

The user level, the AGILEHAND level, and the device communication level are all connected by the access network. Data gathered from the Visible Manufacturing Components is transmitted to the AGILEHAND level through the data collection sub-level. The Visible Manufacturing

Components are controlled by commands either from the user level or the AGILEHAND level through the device control sub-level.

A wired communication network, such as a local area network (LAN), or a wireless communication network, such as a wireless LAN (WLAN) or mobile (GSM) network, can serve as the access network. Regardless of the communication method, the access network often uses IP-based.

Proximity network

The Visible Manufacturing Components and the Device Communication Level are connected by a proximity network. The device communication level sends commands to Visible Manufacturing Components, which are industrial sensors, through this network and receives information from Visible Manufacturing Components, which are industrial devices.

The proximity network could be an Industrial Ethernet or a customized private network. Other protocols beyond IP are used in some networks. However, if a Visible Manufacturing Component is physically affixed to or integrated into the device communication level, the proximity network is not required.

4.2.1. Networking view - Information exchange examples

Errore. L'origine riferimento non è stata trovata. describes how information may be exchanged within AGILEHAND reference architecture using currently available communication protocols.

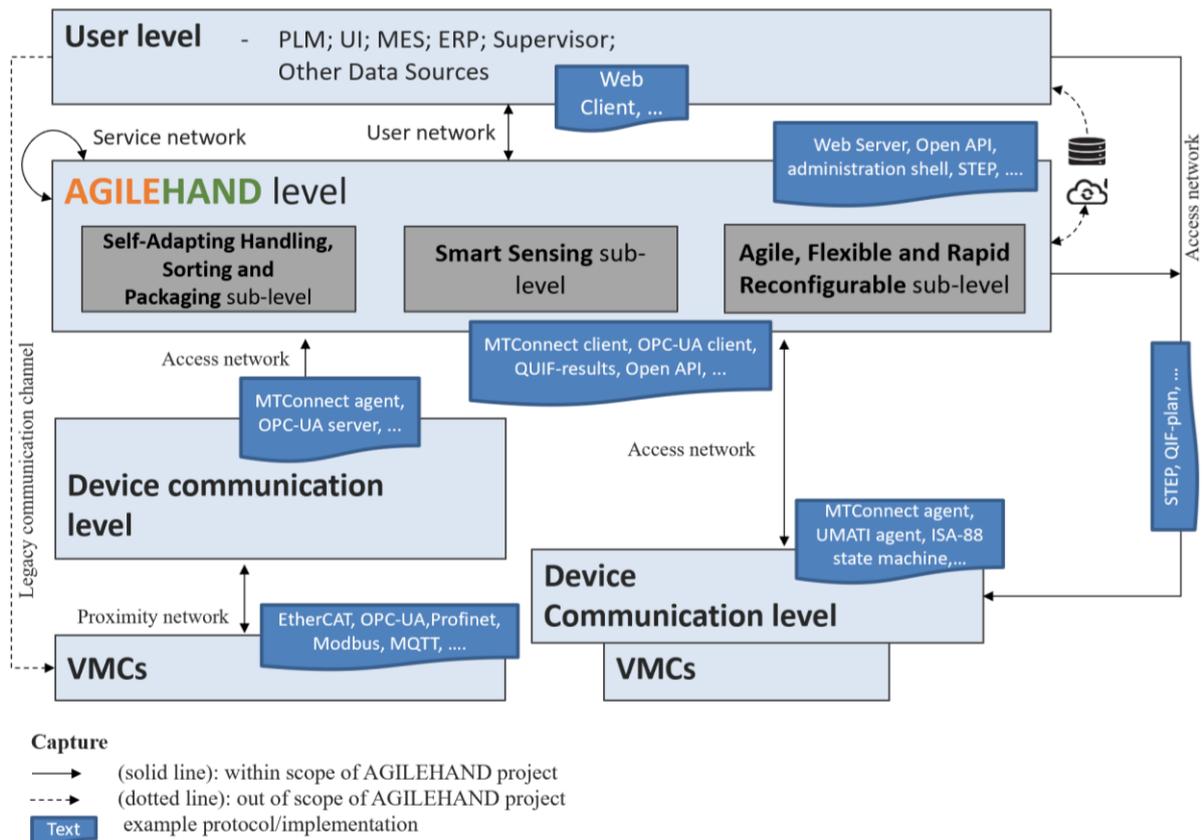


Figure 37. - AGILEHAND information exchange example

There are two Visible Manufacturing Components (VMCs) configurations in Figure 37.

- Data is gathered by the device communication level through the proximity network and delivered to the AGILEHAND level utilizing the access network in the first configuration (i.e., left device communication level/VMCs). Through the legacy communication route, the user level can control the VMCs. As an example, an operator loads a G-Code file into the control after writing it from a PLM.
- The data is directly gathered by the device communication level within a single system in the second configuration (i.e., right device communication level/VMCs), and it is then delivered to the AGILEHAND level utilizing the access network. For instance, a contemporary CNC control might include MTConnect for reporting results as well as direct numerical control for data input.

Implementation options for information exchange in the user network

The implementation options for information exchange in the user network are as follows:

- In terms of standardized techniques for information exchange, the AGILEHAND level can offer HTTP or REST-based web services for the user level;
- Open APIs can be set forth by the AGILEHAND level for the user level. An example of an Open API is a web interface;
 - A database or cloud can be used by both the AGILEHAND level and the user level to share or exchange information;
- Applications like PLM, MES, and ERP can communicate with the AGILEHAND level. Data pertaining to manufacturing can be obtained by the AGILEHAND level via interfaces with these programs;
- The IEC 62264 series (also known as ISA-95), which specifies the automated interface between enterprise and control systems, is one of the standards that could be applied to industrial information. IEC 62264 is implemented in XML by a B2MML. The AGILEHAND can benefit from manufacturing data extracted from the B2MML, such as asset tracking and inventory management. The specifications for software-interfacing that enable the interoperability of manufacturing software tools (modules or systems) are characterized by the ISO 16100 series. The information needed for smooth production planning is defined by the ISO 18828 series;
- Asset administration shell (AAS), a popular meta-model that is used to describe assets in many formats such as JSON, XML, and RDF, can be used to define an AGILEHAND model;

Implementation options for information exchange in the access network

The implementation options for information exchange in the access network are as follows:

- Using protocols like MTConnect and OPC-UA, users can interact with VMCs in terms of standardized information sharing;
- IoT devices (such as sensors and actuators) can be accessed and controlled at the user level using protocols like OPC-UA, OCF, LwM2M, and oneM2M. Different data formats that are transferred in the protocols have been specified by the IoT protocols;

Implementation options for information exchange in the proximity network

The implementation options for information exchange in the proximity network are as follows:

- The proximity network is not required if the VMC is already capable of MTConnect or OPC-UA;
- The VMC can be connected to a proprietary network or industrial ethernet to allow local communication (e.g., EtherCAT, Ethernet/IP, Profinet, Modbus, RAPIENet);

5. Conclusion

The definition of the AGILEHAND reference architecture (RA) is an important step for the success of the project. This architecture establishes a solid and coherent structure that guides the design and implementation of the solutions, starting the analysis of interoperability, scalability and efficiency throughout the process.

It also facilitates collaboration between the different teams and stakeholders by establishing a common language and a shared understanding of the project structure.

Moreover, it provides guidance for implementing AGILEHAND SUITEs in use cases and, more in general, in the manufacturing sector. The architecture makes it easier for stakeholders, such as device manufacturers, application developers, and consumers, to comprehend how AGILEHAND solutions are implemented.

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