D2.1 – i4Q Reference Architecture and Viewpoints Analysis

WP2 – DESIGN: i4Q Framework Design

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ABSTRACT	This document delivers the first release of the i4Q Reference Architecture (RA). A wide range of state-of-the-art standards and open-source frameworks, initiatives and projects have been briefly assessed in order to determine their suitability as baseline assets. All this information has contributed to describe a preliminary version of the i4Q RA based on three tiers: Edge, Platform and Enterprise Tier. Based on the project view, the first version of the i4Q RA proposes main preliminary building blocks. In order to have a coherent inclusive vision provided by the i4Q RA, a first-round mapping with very limited subset of solutions in the RA has been performed. This		

	activity will be finalized during next months and will provide interesting inputs for the final i4Q RA. Finally, the document introduces the four viewpoints (business, usage, functional, implementation viewpoint) which will be analysed in the following months. This task of i4Q RA definition will go on during the next months and will be performed in parallel with those of its viewpoints and information models and ontologies and will lead to the final version.

Document History

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ABBREVIATIONS/ACRONYMS

AAS	Asset Administration Shell
AI	Artificial Intelligence
AF	Architecture Framework
API	Application Programming Interface
AQ	Autonomous Quality
BDA	Big Data Analytics
BDVA	Big Data Value Association
C2NET	Cloud Collaborative Manufacturing Networks
CEP	Complex Event Processing
CPS	Cyber Physical System
CPV	Critical Process Variable
CREMA	Cloud-based Rapid Elastic Manufacturing
DAIRO	Data, AI and Robotics Association
DFA	Digital Factory Alliance
DIN	Deutsches Institut für Normung
DoA	Description of Action
DSA	Digital Shopfloor Alliance
DS-RA	Digital Service Reference Architecture
DSS	Decision Support System
DT	Digital Transformation
ERP	Enterprise Resource Planning
FaaS	Fog as a Service
FOF	Factories of the Future
GDP	Gross domestic product
HPC	High Performance Computing
ICT	Information and communications technology
IDSA	International Data Spaces Association
IEC	International Electrotechnical Commission

IEEE	Institute of Electrical and Electronics Engineers
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
IPR	Intellectual Property Rights
ISO	International Organization for Standardization
IT	Information technology
I4MS	ICT Innovation for Manufacturing SMEs
MES	Manufacturing Execution System
OPC UA	Open Platform Communications United Architecture
OT	Operational Technology
PAS	Publicly Available Specification
PPP	Public Private Partnership
RA	Reference Architecture
RAF	Reference Architecture Framework
RF	Reference Framework
RAMI4.0	Reference Architectural Model Industry 4.0
RAS	Reliability, Availability, and Serviceability
REST	Representational State Transfer
RIDS	Reliable Industrial Data Services
SDK	Software Development Kit
SOA	Service Oriented Architecture
SRIA	Strategic Research and Innovation Agenda
SSL	Secure Sockets Layer
vf-OS	Virtual Factory Operating System
ZDM	Zero-Defects Manufacturing
ZDMP	Zero Defects Manufacturing Platform

Executive summary

i4Q Project aims to provide a complete set of solutions consisting of IoT-based Reliable Industrial Data Services (RIDS), the so called 22 i4Q Solutions, able to manage the huge amount of industrial data coming from cheap cost-effective, smart, and small size interconnected factory devices for supporting manufacturing online monitoring and control.

One of the challenges in implementing quality control processes and solutions is the development of the **i4Q Reference Architecture (i4Q RA)** for industrial data services in smart manufacturing, based on innovative technologies and on relevant sector-specific standards.

This document delivers the first release of the i4Q RA, representing the first output of Task 2.1. T2.1 "i4Q Reference Framework" is devoted to the design of an architecture for IoT-based **Reliable Industrial Data Services (RIDS)** ready to deal with large amounts of data. To this purpose, the conceptualisation of the i4Q Reference Architecture follows the ISO/IEC/IEEE 42010 "Systems and software engineering – Architecture", starting from a deep understanding and alignment among the most common reference architectures in the manufacturing domain.

The i4Q RA is not designed from scratch, being strongly based on the most relevant outcomes of other previous Research and Innovation activities. To this end, several research projects have already been executed by many of the Consortium partners, providing a wide set of background knowledge on the topic and representing solid backgrounds to stem upon.

On the other hand, this document goes deeper into the state of the art and presents an analysis of the most recent releases of some relevant standard reference architectures for digital industries, industrial IoT and edge computing - namely those from the Platform Industrie 4.0 initiative (RAMI 4.0), the Industrial Internet Consortium (IIRA and OpenFog RA), the Big Data Value Association (BDVA RA), Digital Factory Alliance Initiative (Digital Service RA), the ISO Standard for Internet of Things (ISO / IEC 30141).

Firstly, a wide range of state-of-the-art standards and open-source frameworks, platforms and tools have been briefly assessed in order to determine their suitability as baseline assets.

Following these experiences, results from previous projects (especially those ones dealing with the Zero-Defect Manufacturing issues) have been adopted as the main input to further enhance them for quality control in smart manufacturing scenarios, exploiting their adherence to standards and the openness toward the integration of multiple digital enablers.

To achieve this goal, a preliminary version of the i4Q RA is presented in this report: it groups the components into three main tiers, Edge Tier, Platform Tier and Enterprise Tier. The three-tiers approach is inspired by the IIRA architectural model, and tiers are hierarchically stacked according to their scope with respect to the physical processes in the factory.

This task of i4Q RA definition will go on during the next months and will be performed in parallel with those of its viewpoints (namely T2.3, T2.4, T2.5, T2.6); viewpoints will offer a framework to think iteratively through the architectural issues that may arise during its conception.

All of the information gathered in this deliverable will lay the groundwork for future project steps.

Document structure

Section 1 Methodology: Definition of Reference Architecture concept and Conceptualization of a system's architecture, according to the ISO/IEC/IEEE 42010 "Systems and software engineering – Architecture" standard.

Section 2 Background and Vision: Introduction to the context, i.e., industrial sector, with focus on quality control for production and processes. State of the art of the most relevant running and completed initiatives and solutions at European level dealing with production quality control in smart manufacturing.

Section 3 Relevant Initiatives and Reference Architectures: Investigation on the most recent releases of some relevant generic reference architectures for digital industries.

Section 4 i4Q Architectural Framework: Preliminary version of the i4Q Reference Architecture (i4Q RA).

Section 5 i4Q RA: main viewpoints: Presentation of the main viewpoints which will drive the design and implementation of the i4Q Reference Framework (i4Q RF).

Section 6 Conclusions and Next Steps: Activities planned for the next periods, input and output to define the final version for the i4Q RF.

1. Methodology

The fast-growing number of implementations of Digital Manufacturing Platforms and the existing fragmentation of OT/IT systems already available on the shopfloors have triggered various initiatives to define Reference Architectures (RAs) for the industry. A RA provides guidance for the development of a system, solution and application architecture and provides common and consistent understanding for the system, as well as its decompositions and interaction patterns. RAs provide a high level of abstraction that is applicable to many actual implementations of the system, coping with different business objectives and technologies adopted.

Conceptualization of a system's architecture, as defined in the ISO/IEC/IEEE 42010 "Systems and software engineering – Architecture" (ISO, 2011) standard, assists the understanding of that system's essence and key properties related to its behaviour and composition. It describes the structure of the system with its entities, as well as the interactions between each entity and the environment. RAs are used as generic guidelines that abstract the specific needs and technologies of various implementations and use cases. Generally speaking, the RAs provide (Sadiku, Wang, Cui, & Musa, 2017):

- a common lexicon that facilitates communication
- a common (architectural) vision that focuses and aligns efforts of multiple people and teams
- modularisation to divide the effort and the complementary context that ensures later integration
- guidance and baselines
- articulation of domain and realization concepts

This document presents the Reference Architecture of i4Q Solutions, based on the use of multiple, concurrent views. Multiple views allow to address separately the concerns of the various stakeholders of the i4Q project, mainly technical partners and business partners, and to handle the functional and non-functional requirements individually. The **i4Q Reference Architecture (i4Q RA)** will be designed using an architecture-centered, scenario-driven, iterative development process.

The i4Q RA deals with the design, implementation and deployment of complex Digital Manufacturing Platforms able to realize the Quality concept foreseen within the whole project. It is the result of assembling a certain number of architectural components, integrating existing digital technologies and organization processes with several outcomes of i4Q, in some well-chosen forms to satisfy the major functional and non-functional requirements of the system described in other project deliverables (mainly D1.4 and D1.9).

Following the terminology defined in the ISO/IEC/IEEE 42010 (ISO, 2011), an architecture description expresses an architecture of a system of interest. While an *architecture* can be abstract, consisting of concepts and properties, an *Architecture Description* is a work product formalizing an architecture, including one or more architecture views. An *Architecture View* addresses one or more of the *Concerns* held by the system's *Stakeholders*. An architecture view expresses the architecture of the system of interest in accordance with an *Architecture Viewpoint* (or simply, viewpoint). To this end, an *Architecture Framework (AF)* contains the conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders. The AF can be described following several dimensions, establishing the conventions for the construction, interpretation and use of architecture of a system from the perspective of specific system concerns.

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

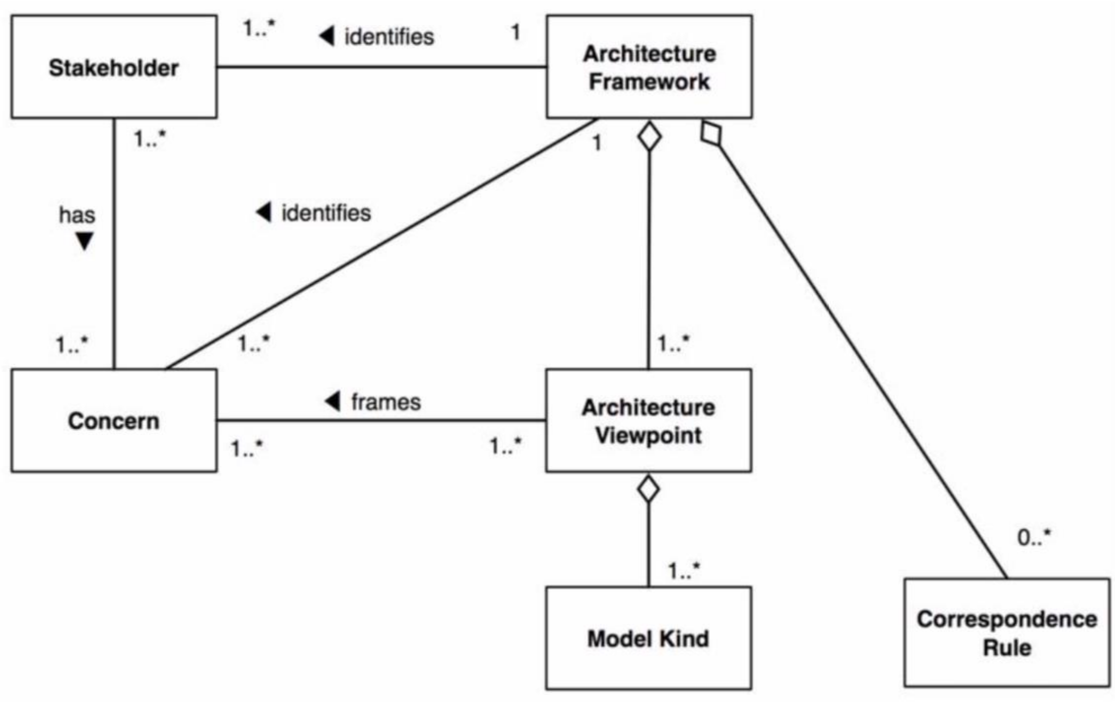

Figure 1. The Architecture Framework entity model in ISO/IEC/IEEE 42010

In the context of the i4Q Architecture Framework (further described in Section 4 and 5), the most relevant viewpoints specified are the following: Business View, Usage View, Functional View and Implementation View.

Apart from adherence to the above methodological approach, the present deliverable has taken into account several existing Reference Architectures in the world-wide community, as well as several mapping and alignment handover still undergoing and aiming to harmonize the different angles used in the different approaches dealing with Reference Architecture for manufacturing, as presented in the following Section 2 and 3.

2. Background and Vision

2.1 Project Background

One of the main sectors for the European Union's economy is the industrial sector. Not only does it generate employment, but it also provides 14% of European GDP[1]. This sector is made up of 2 million companies and provides more than 33 million jobs. The manufacturing sector generated EUR 5.812 Billion of turnover and EUR 1.400 Billion of added value.

One of the main challenges for manufacturing companies is to adjust and redesign their manufacturing systems to adapt it to different requirements without losing quality. In addition, it allows to limit the use of resources while reducing costs. In this context, the complementation of zero-defects strategies plays a decisive role.

Over the past decades, European manufacturing companies have been looking for the best way to optimize quality through different methodologies and tools. Whether using sensors or automated processes, their goal has always been to improve quality management and reduce variability in the manufacturing of assets. On the other side, during the last decade, R&D has focused on solutions based on zero-defect quality control to improve process control performance. However, current solutions have three drawbacks:

- **Data management**: Due to the digital transformation and centralization of data, it is possible to find numerous sensors, actuators, and instruments inside the manufacturing lines, which provide users with a lot of data during the manufacturing process. Through this technology a very valuable basis for improving quality is obtained in manufacturing. The problem is that most European factories fail to analyse the data generated in the daily process.
- **Complexity**: The degree of complexity of data analysis or the technological needs to capture it makes it inaccessible to small companies. Not only because of the economic cost, but also because of the complexity of the analysis involved in dealing with this data. Advanced data science or IT skills are usually required, and most current solutions do not provide direct support for analysis or facilities such as reporting or predictive tools.
- **Dynamic behaviour of the manufacturing factories**: They require data fusion, modelling and simulation techniques to be able to interpret all the data collected from the different points in the interdependent systems.

Since the third industrial revolution, the emergence of digital information storage of the company has appeared. Thanks to the technological advances of the last decades, these data collection points are growing exponentially (Shao, Shin, & Jain, 2015). However, there are few sectors or manufacturing companies that are really taking advantage of all this collected data and generating improvements in their production processes (Jain, Shao, & Shin, 2017).

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[1] https://data.worldbank.org/indicator/NV.IND.MANF.ZS?locations=EU

Recently, the application of data analytics (the process of finding useful information from the analysis of data generated by manufacturing) has been presented as a solution to the issue of capitalising on ever-growing manufacturing data (Lade, Ghosh, & Srinivasan, 2017). However, whether for decision making or production optimisation, the goal is to apply big data analytics (BDA) to smart manufacturing in the future, in a way that helps business managers learn to predict the future using everything they have done today (Shao, Shin, & Jain, 2015), (Dai, Wang, Xu, Wan, & Imran, 2020). This whole taxonomy focuses on four types of analytic processes: diagnostic, descriptive, prescriptive, and predictive. Prescriptive and predictive analytical approaches are proactive, while descriptive and diagnostic analytical methods are relative:

1. Descriptive analysis: This process of exploratory analysis is related to analysing historical data to learn about the past. Through this process or step, characteristics of the data can be revealed, or patterns can be recognized that identify relationships between different circumstances.
2. Diagnostic analytics: This analysing process is a deeper look at the data that seeks to understand the causes of some behaviours or events of machines and other equipment. In this way, we can identify and predict possible failures or breakdowns and thus avoid system downtime.
3. Predictive analytics: This process uses historical data to anticipate what will happen in the future.
4. Prescriptive analytics: This process extends the results of descriptive, predictive, and diagnostic analytics to obtain the needed data that will help making decisions to achieve the expected results. Prediction, decision making, learning and optimisation algorithms are used for this process. It is seen as a future challenge in manufacturing data analytics (Jain, Shao, & Shin, 2017) and is closely related to Digital Twin and optimisation.

This whole process of information storage and analysis generates a large volume of data (Batini, Cappiello, Francalanci, & Maurino, 2009), so much that we have come to relate the concept of "smart factory" to data-driven manufacturing (Wang, 1996). This allows companies to visualise, analyse and react almost in real time to different areas of manufacturing (production, order management, supply chains...). Moreover, with all this data, daily planning can be carried out at a strategic or business level. We can identify common measures that define a set of data quality attributes in five dimensions: accuracy, completeness, consistency, timeliness and accessibility.

- **Accuracy**: Defines two types, syntactic (assessing the closeness of a data value in a defined set within a syntactically correct domain) and semantic (assessing closeness from a semantic point of view).
- **Completeness**: This measures the degree to which data describe a set of real-world objects. It often focuses on the presence and meaning of null values; hence it is often associated with a Boolean value.
- **Consistency**: It tries to comply with the semantic rules defined on the data (it answers questions such as: "are the data coherent between data sets" and "do the data represent contradictory information").
- **Timeliness**: Specifies the freshness of the data with respect to its use.

- **Accessibility**: refers to the ability of users to access all data generated within a context.

I4Q project RIDS (Reliable Industrial Data Services) solution based on the Internet of things (IoT). This is a complete suite based on 22 i4Q Solutions that can manage a large amount of industrial data. All these solutions are modular with a Reference Architecture, focused on the manufacturing sector, based on the current standards of the manufacturing industry (IIRA RAMI4.0, IDSA and IMSA). The i4Q Solutions range from basic layers (network, middleware, databases) to the fundamental viewpoints involved in the processes (business, usage, operation, and implementation). Its goal is to improve digital manufacturing through reliable and efficient data collection and analysis. To this end, it supports the entire industrial data flow (from collection to prediction) by offering solutions that guarantee data security and reliability. All this with solutions adapted to manufacturing, such as Blockchain-based services or distributed storage.

i4Q contains a set of services including data fusion and integration, data analytics and data distribution. Thanks to it AI workloads (even at the edge) can be enabled and managed through dedicated services for further dynamic deployment in cloud/edge architecture scenarios. i4Q provides an all-level view through scalable monitoring, data, and resource management tools. All this by mapping to different workloads, intelligent alerting, or fault prediction.

Thanks to the use of digital twins, we can fully digitise the manufacturing process, which provides the company with simulation and modelling capabilities. This allows to analyse the parameters that generate a process and how it affects the quality of the final product. In addition, the digital twins focus on quality diagnostics on the manufacturing line. With i4Q we can implement an automated continuous qualification process and the use of real-time data. To facilitate broad and agile deployment, i4Q has a modular microservices-based approach, which allows the component framework to be adapted and integrated into various manufacturing scenarios, regardless of the company or different maturity levels.

The goal of i4Q RIDS is for factories to be able to manage large amounts of data, achieving appropriate levels of precision, accuracy and traceability. Using this data to analyse and predict future factory behaviour and optimise the quality of processes and manufactured products, leading to a zero-defect approach to manufacturing.

i4Q Solutions efficiently collect all industrial data in raw form. It uses state-of-the-art communication protocols, guaranteeing the accuracy and precision of the data. This provides reliable traceability and integrity of all data. i4Q provides optimisation and simulation tools for continuous process qualification of the manufacturing line. Generating quality diagnostics, reconfigurable and certified, ensuring high efficiency and quality.

2.2 State of the art in Digital Manufacturing Platforms and Initiatives for Quality Control

Manufacturing industries are continuously facing the challenge of operating their manufacturing processes in order to deliver the required production rates of high-quality products, while minimizing the use of resources. Concerning quality control in smart manufacturing, several approaches have been arising in recent years; e.g., Zero Defects Manufacturing (ZDM) is aiming at going beyond traditional six-sigma approaches.

Innovative and integrated quality, production logistics and maintenance design, management and control methods as well as advanced technological enablers play a key role to achieve the overall production quality goal.

The main objectives of quality control approaches are to get zero defects in a production environment (i.e., to get it right at the first time), to achieve waste/scrap reduction, lower production costs, shorter production times, higher productivity and competitiveness, and last but not least, a higher resource and energy efficiency. All those goals should bring a significant competitiveness increase and job creation for the EU manufacturing industry.

Among the challenges that the quality control approach (e.g., ZDM) brings to industries, it is worth to highlight the identification of error sources and types, the clustering of errors (and subsequent solutions) according to the most common levels in an industrial shop-floor activity, and finally, the development and implementation of suitable tools as solutions for the upstream generation and downstream propagation of production defects.

Regarding the above mentioned zero-defects levels, the ZDM paradigm in an industrial factory approach may be composed by several relevant fields and layers.

- Process level: on one hand, workpiece-fixturing-clamping, components and machine, manufacturing process (in where error sources are located and ZDM tools should be implemented).
- Multi-stage system level: on the other hand, interconnected manufacturing cells and shopfloor/workshop dimension, where data acquisition and processing, data monitoring, process prediction and optimization become more critical.

An integrated approach to quality, safety, maintenance, lead time and productivity is requested. It should be supported by:

- Zero-defects manufacturing approaches at process levels (to identify error sources and to avoid error propagation downstream);
- In-line quality acquisition, before, during and after the process;
- Data mining and data analytics through advanced sensing and integrated approach through the manufacturing chain.

Digital Manufacturing Platforms play an increasing role in dealing with competitive pressures and incorporating new technologies, applications and services. The challenge is to make full use of new technologies that enable manufacturing businesses. Several actions (i.e., innovation and research actions, coordination and support activities) cross-fertilize the industrial platform communities, facilitating the adoption of digital technologies from ongoing and past research projects to real-world use cases and encouraging the transfer of skills and know-how between industry and academia.

In platform building, new activities need to develop next-generation digital platforms, which build on the state of the art, reuse what is available, and integrate different technologies, such as IoT, AI, robotics, cloud and Big Data. Platforms should aim at openness and interoperability between platforms to avoid lock-in, prevent dominant positions of individual players, and comply with standards and regulation. Proposals need to target solutions also for SMEs and mid-caps, taking into account interoperability with emerging and future solutions.

This may require the mapping of referent architecture models for integrating existing sectorial platforms. The interfaces of the platforms need to be described via open specifications and reference implementations need to be developed. A major aim is to offer platform functionalities that can be generically reused in multiple contexts to support various types of applications and services.

The findings of the research work show the broad and complex scope of digital manufacturing platforms. The relationship between private (IoT platform vendors, manufacturing equipment suppliers and machine tool builders) and public stakeholders (European Commission, Public Private Partnerships, etc.) in the strategy of digitizing the European industry contributes to build a global vision towards addressing future challenges posed by the need to create new business models based on data economy and the growth of digital ecosystems fostered by digital manufacturing platforms.

The development of digital manufacturing platforms is in an early stage but supported in a mature IoT ground. In spite of the relevant advances achieved so far, there is still a lot to do in order to connect to additional services according to the 'plug-and-play' philosophy and considering the multi-sided ecosystem of service providers, platform providers and manufacturing companies, mechanisms for the commercial or open-source provision of the digital services through appropriate marketplaces, legacy system integration, etc.

In this chapter the main solutions and initiatives will be explored. The focus will be on relevant projects at European level, both ongoing and completed. These projects represent an interesting starting point both for the addressed issue of quality management and for the technological methodology here explained to face the problem (e.g., IoT, Big Data, etc.).

The analysis carried out has included possible interesting initiatives and technological solutions that could help in dealing with the quality issues addressed. This section is based on the relevant contribution of all the project partners, who have contributed with their background and experiences to provide valuable input for future considerations. Feedback was collected through a survey submitted to all partners (see Appendix I). The architectures and technological solutions presented will be an inspiration for the i4Q Reference Architecture.

2.2.1 Zero Defects Manufacturing Platform

2.2.1.1 Overview

ZDMP[2] was born from the idea of providing an extensible platform to support factories with a high level of interoperability, so that the goal of zero defects is achieved thanks to the connected factory concept. Thanks to this architecture (**Figure *2***), ZDMP will be able to connect the ERP and

[2] https://zdmp.eu/

plant systems, improving quality and increasing production benefits, among others. In addition, it provides many design options within the entire architecture.

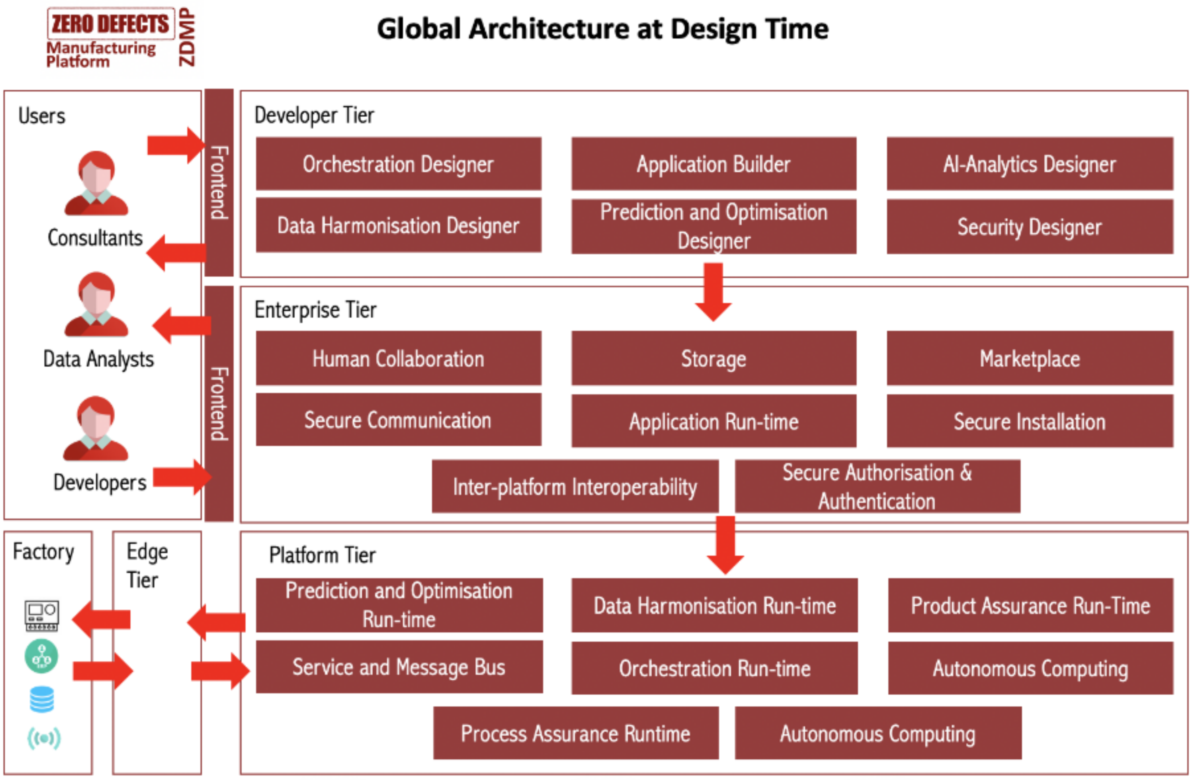

Figure 2. ZDMP Architecture at Design Time

ZDMP provides a dedicated app store where you can get apps based on factory needs. Users or third-party companies can develop new applications thanks to the ZDMP SDK (Software Development Kit), which provides developers with all the necessary tools, and integrate them into the platform.

ZDMP[3] uses outcomes/concepts developed in other research projects, such as Cloud-based Rapid Elastic Manufacturing (CREMA), Cloud Collaborative Manufacturing Networks (C2NET), or Virtual Factory Operating System (vf-Os). ZDMP aims to ensure the quality of the production process and dedicated workstreams.

Launched in 2019, the 4-year Zero Defects Manufacturing Platform (ZDMP) activity develops platforms for achieving excellence in manufacturing through zero defect processes and products. To this end, it integrates various technologies, based on the following principles[4]:

[3] https://www.zdmp.eu/foundation-projects
[4] https://angry-spence-1ecc9e.netlify.app/docs/overview/

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

2.2.1.2 Main features

The features provided by ZDMP can be separated into the following categories:

- **zComponents:** These components fully belong to the ZDMP platform and provide core functionalities that can be used by other sources. An example is Al-Analytics Run-time, which allows to implement the functionality of running automatic learning models based on production data obtained in real time. In this way, potential errors that could cause losses within the factory are avoided. All these components of ZDMP can be used by external platforms to increase their AI capabilities and be used by different applications.
- **zApps:** These are applications of the ZDMP Platform that provide one specific functionality. To do so, it uses both ZDMP platform components, such as AI-Analytics Run-time and other zApps. An example would be zAnomalyDetector, which performs extensive analysis to detect anomalies in real time.

2.2.1.3 Potential interest for i4Q

One of the core aspects of the ZDMP project is the interoperability and connection with third-party platforms, expanding functionalities and improving the usefulness for all its users. Moreover, it evaluates the different third-party platforms for interconnections and defines which characteristics must be interconnected to obtain benefits, both from a technical and a business level point of view. This project can be of base of developing and integrating the i4Q Solutions. The Platform core services provide a runtime environment that can support the deployment of i4Q Solutions as additional components, so that they can be usable in ZDMP.

2.2.2 QU4LITY

2.2.2.1 *Overview*

QU4LITY[5] has started at January 1, 2019 and will last 39 months (March 2022). It represents one of the most advanced projects dealing with building Digital Platforms focusing on data spaces and IoT interoperability.

QU4LITY is developing and deploying solutions for the next generation of Zero-Defect Manufacturing (ZDM) capabilities in the Industry4.0 era. The project's solutions will therefore leverage Cyber Physical Systems (CPS) and advanced digital technologies (e.g., Big Data, Edge/Fog Computing, Artificial Intelligence). QU4LITY is concerned not only with demonstrating Industry4.0 ZDM solutions in productions lines, but also with providing reusable building blocks for developing and integrating such solutions.

QU4LITY will demonstrate, in a realistic, measurable and replicable way an open, certifiable and highly standardised, SME-friendly and transformative shared data-driven ZDM product and service model for Factory 4.0 through 14 pilot lines.

QU4LITY will also demonstrate how European industry can build unique and highly tailored ZDM strategies and competitive advantages through an orchestrated open platform ecosystem, ZDM atomized components and digital enablers across all phases of product and process lifecycle. The main goal is to build an autonomous quality model to meet the Industry 4.0 ZDM challenges.

2.2.2.2 *Main features*

The QU4LITY RA[6] is aligned to the implementation needs envisaged in the Autonomous Quality (AQ) vision defined in the project, where processes and solutions are developed toward innovative digital ZDM solutions for smart manufacturing, based on best-in-class technologies and on relevant sector standards. To this end, the QU4LITY RA has not been designed from scratch, being strongly based on the most relevant outcomes of other Research and Innovation activities and strongly rooted back on the Platform Industrie 4.0 initiative (RAMI 4.0) and the Industrial Internet Consortium (IIRA and OpenFog RA).

The Digital Shopfloor Alliance Reference Framework has been adopted as the main input to further enhance it for ZDM scenarios, exploiting its adherence to standards and the openness toward the integration of multiple digital enablers.

The following figure (**Figure *3***) illustrates different components and views of the QU4LITY Reference Architecture (QU4LITY RA).

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[5] https://qu4lity-project.eu/

[6] https://qu4lity.ems-innovalia.org/nfs/programme_5/call_3/call_preparation/QU4LITY_D2.11_v1.0.pdf

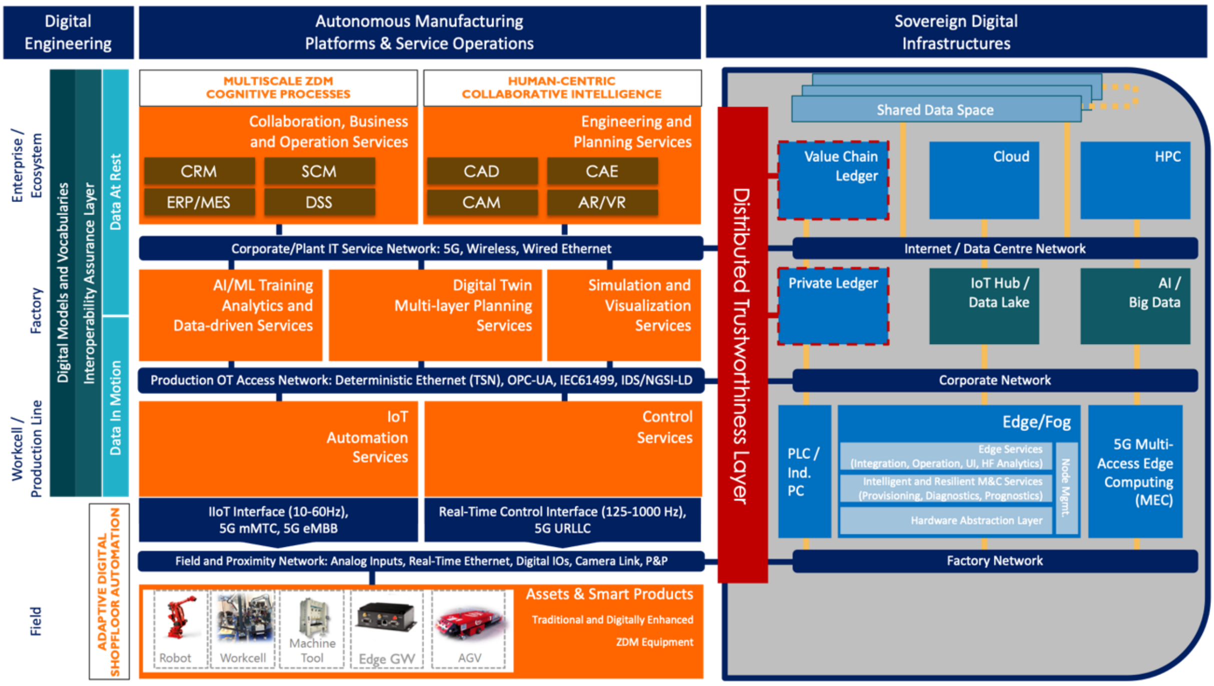

Figure 3. QU4LITY Reference Architecture

QU4LITY RA as a Four-Tier design, where the main Tiers (Field, Line, Factory and Ecosystem) are hierarchically stacked according to their scope with respect to the physical processes in the factory, and one Digital Infrastructure providing common services such as connectivity and distributed processing capabilities. Moreover, the QU4LITY RA groups 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, and Crosscutting Functions (Security, Sovereign Digital Infrastructures, and Digital Models and Vocabularies) that are domain-agnostic.

2.2.2.3 Potential interest for i4Q

QU4LITY will realise a radical shift from state-of-the-art production quality methods to the disruptive Autonomous Quality (AQ) concept, through enabling manufacturers and solution providers (including SMEs) to develop, validate, deploy and adopt innovative Cognitive Manufacturing solutions for ZDM. The multi-perspective approach and technology independent AI-driven solutions will be of inspiration of developing and integrating the i4Q Solutions.

2.2.3 IoTwins

2.2.3.1 Overview

The focus of IoTwins is to lower the barriers for the uptake of Industry 4.0 technologies to optimize processes and increase productivity, safety, resilience, and environmental impact. Its approach is based on a technological platform allowing a simple and low-cost access to big data analytics functionality, AI services and edge / cloud infrastructure for the delivery of digital twins in manufacturing and facility management sectors.

IoTwins started at the 1st of September 2019 and with a duration of 3 years (August 2022).

2.2.3.2 *Main features*

The project will focus on building a reference architecture for the development and deployment of distributed and edge-enabled digital twins of production plants and processes. The digital twins will collect data from the manufacturing, maintenance, operations, facilities and operating environments. Based on the collected data, models of each specific assets, system or process will be created. The project will provide[7]:

- **A reference architecture** for the interaction of distributed cloud-, edge- and IoT-hosted digital twins.
- **An edge computing framework** supporting the dynamic deployment of digital twins including control models. Additionally, orchestration of reconfiguration methods together with cloud-based solutions will be investigated.
- **Vertical and distributed digital twins** enabling online quality management and optimization of manufacturing processes.
- **Well-assessed methodology for replicability** demonstrating the applicability of the solutions to many different application sectors with similar requirements and goals.

2.2.3.3 *Potential interest for i4Q*

Contributions from IoTwins can be evaluated and be used as basis for the work in i4Q. The developed reference architecture targeting distributed cloud and edge solutions for data handling can be investigated as a basis for the development of the i4Q reference architecture. Furthermore, the concept and design of the distributed digital twin to enable improved production processes can be of importance to the technologies developed inside i4Q.

2.2.4 OPEN DEI

2.2.4.1 *Overview*

The digital transformation strategy of the European Union has, among others, a particular priority: the creation of common data platforms based on a unified architecture and an established standard. As part of the **Horizon 2020 programme**, the OPEN DEI (Aligning Reference Architectures, Open Platforms and Large-Scale Pilots in Digitising European Industry) project focuses on "Platforms and Pilots" to support the implementation of next generation digital platforms in four basic industrial domains: Manufacturing, Agriculture, Energy, Healthcare.

OPEN DEI[8] has started at the 1st of June 2019 and will last 36 months (May 2022). It aims to be an essential pillar of the implementation of Digitising European Industry policies: the project aims to provide the necessary measures, channels and mechanisms to ensure cooperation between pilot projects so that synergies can be exploited, knowledge can be shared, and impact is maximized.

OPEN DEI strives to implement four action lines:

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[7] https://www.iotwins.eu/

[8] https://www.opendei.eu/

- **Platform building:** Comparing reference architectures and open source reference implementations, enabling a unified industrial data platform.
- **Large scale piloting**: Contributing to a digital maturity model, creating a set of assessment methods and a migration journey benchmarking tool.
- **Data ecosystem building:** Enabling an innovation and collaboration platform, forging a European network of DIHs, contributing to industrial skills catalogue and observatory.
- **Standardisation:** Conducting cross-domain surveys, performing promotion and implementation, building alliances with existing EU and standard developing organisations.

2.2.4.2 Main features

Within OPEN DEI, one important objective aims at harmonizing and coordinating different Digital Transformation (DT) approaches under a common **Reference Architecture Framework** (RAF), which combines knowledge and tools to foster effective sharing and assessment of experiences and lessons learned on how systems supporting DT can be architected, crossing the boundaries of specific applicative sectors.

OPEN DEI proposes a conceptual model for integrated data-driven services for Digital Transformation pathways, to guide their planning, development, operation and maintenance by adopting organizations. The model is modular and comprises loosely coupled service components interconnected through a shared common data infrastructure.

The OPEN DEI project has defined the approach for designing a common Reference Architecture Framework able to describe the Cross Domain Digital Transformation[9].

The extensive use of sensors and connected devices is a common scenario in the implementation of many Digital Transformation solutions and in many industrial sectors. The huge amount of available data is able to cover many business scenarios. Data-driven pipelines and workflows management is nowadays crucial for data gathering, processing, and decision support. To cope with this complexity OPEN DEI has adopted the following 6C architecture, adapted from the one suggested by the German Industrie 4.0 initiative, and based on the following pillars (using a bottom-up reading):

- **Connection**, making data available from/to different networks, connecting systems and digital platforms, starting from the capability to make data available from/to different physical and digital assets.
- **Cyber**, modeling and in-memory based solutions to convert data into information, leveraging several information conversion mechanisms.
- **Computing**, storing and using data on the edge or on cloud.
- **Content/Context**, correlating collected data for extracting information, creating a digital space for data-information continuum, not something to push out to one side of the adopted information architecture.

[9] https://www.opendei.eu/wp-content/uploads/2020/10/D2.1-REF-ARCH-FOR-CROSS-DOMAIN-DT-V1_UPDATED.pdf

- **Community**, sharing data between people and connecting stakeholders for solving collaboration needs.
- **Customization**, personalizing allows to add value to data following each own user perspective and to match their expectations.

The above-mentioned 6C Architecture principles have driven the design of the OPEN DEI RAF, developed around the main concept of Data Spaces in which data is shared (published and accessed), identifying three main different layers described in the following using a bottom-up reading approach:

- **Field Level Data Spaces**, it includes the Smart World Services able to collect data and support the interaction with the IoT Systems (configuration, calibration, data acquisition, actuation, etc.), Automation and Smart Assets (robots, machinery, and related operations) and Human Systems (manual operations, supervision, and control, etc.).
- **Edge Level Data Spaces**, it defines the typical edge operations from the data acquisition (from the logical perspective) to the data processing through the data brokering. The edge services will play a key role also for data analytics (i.e., validating and improving models for data analysis).
- **Cloud Level Data Spaces**, it includes data storage, data integration and data intelligence operations on the cloud. The cloud services will process big data, deploy algorithms, integrate different source platforms and services, provide advanced services such as AI prediction and reasoning.

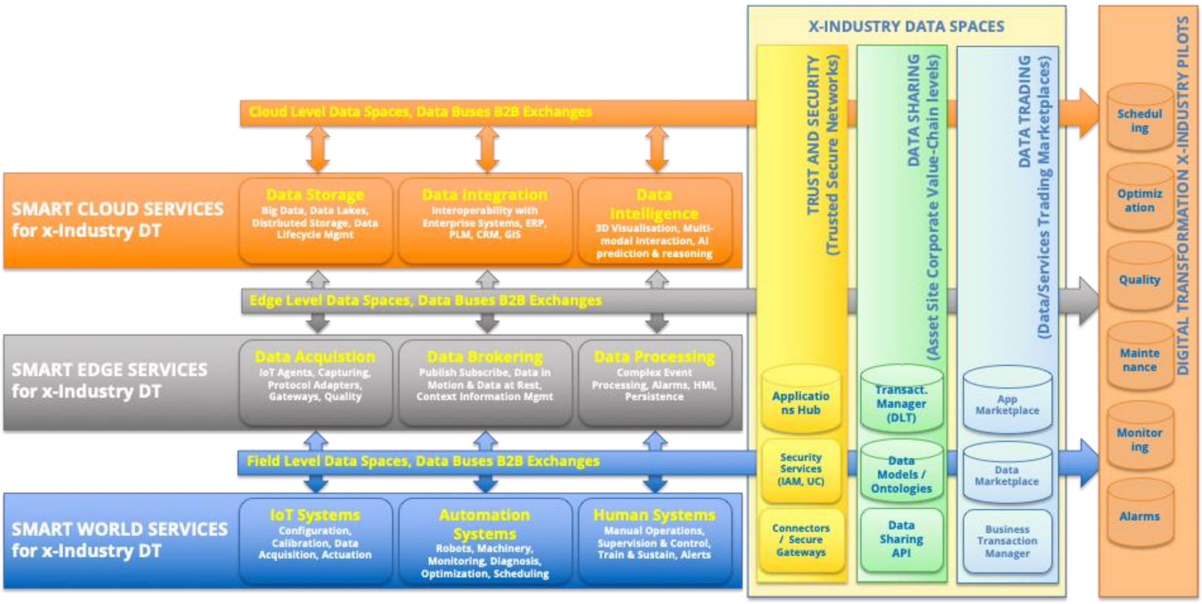

Figure 4. OPEN DEI Reference Architecture Framework

Furthermore, all these horizontal Data Spaces spines will feed the OPEN DEI Reference Architecture Framework a main orthogonal dimension, named **X-Industry Data Spaces**, characterized by following components:

- **Trusted and Security**, incorporating technical frameworks and infrastructures that complements the previous to support trusted and secure exchange, which embraces:

- Applications Hub, an infrastructure which collects the recipes required for the provision of applications (e.g. deployment, configuration and activation) in a manner that related data access/usage control policies can be enforced.
    - **Security Services**, a technical framework to support Identity Access Management, Usage Control and other security services.
    - **Connectors and Secure Gateways**, a technical framework for trusted connection among involved parties.
- **Data Sharing**, incorporating technical frameworks and infrastructures for an effective and auditable data sharing, which more specifically embraces:
    - **Transaction Manager**, a distributed ledger/blockchain infrastructure for logging selected data sharing transactions.
    - **Data Models and Ontologies**, to leverage common standard and information representations.
    - **Data Sharing API**, a technical framework for effective data sharing.
- **Data Trading**, incorporating technical frameworks and infrastructures for the trading (offering, monetization) of data, which embraces:
    - **App Marketplace**, enabling the offering of applications and application building blocks which can be integrated plug&play to enrich existing data spaces.
    - **Data Marketplace**, enabling the offerings around data resources with associated terms and conditions including data usage/access control policies as well as pricing schemas.
    - **Business Support Functions**, enabling data/applications usage accounting as well as implementing Clearing House, Payment and Billing functions.

Finally, all the mentioned layers serve the realization of **Digital Transformation X-Industry Pilots**, for enabling applications (sometimes sector specific) for supporting business scenarios from experiments.

2.2.4.3 Potential interest for i4Q

The conceptual model promotes the idea of interoperability by design. It means that for the to-be integrated services to be interoperable, they should be designed in accordance with the proposed model, or at least mapped to it, and with certain interoperability and reusability requirements in mind. Interoperability and adherence to data models will be an important element in the i4Q ecosystem, considering the broad-spectrum of raw and processed data that can be processed by the different solutions. The openness or, at least, the potential openness to the data spaces should be considered in order to implement the B2B data exchange at the ecosystem level.

2.2.5 BOOST4.0

2.2.5.1 Overview

Boost 4.0 is the biggest European initiative in Big Data for Industry 4.0. Boost 4.0 lead the construction of the European Industrial Data Space to improve the competitiveness of Industry 4.0 and guided the European manufacturing industry in the introduction of Big Data in the factory, providing the industrial sector with the necessary tools to obtain the maximum benefit of Big Data. The main objectives of BOOST 4.0 are[10]:

- Contribution to the international standardization of European Industrial Data Space data models and open interfaces aligned with the European Reference Architectural Model Industry 4.0 (RAMI 4.0).
- Adaptation and extension of cloud and edge digital infra-structures to ensure high performance operation of the European Industrial Data Space; i,e., support of high-speed processing and analysis of huge and very heterogeneous industrial data sources.
- Integration of the four main open-source European initiatives (Industrial Data Space, FIWARE, Big Data Europe) to support the development of open connectors and big data middleware with native blockchain support in the European Industrial Data Space.
- Open interfaces for the development of big data pipelines for advanced analysis services and data visualization supported by the main digital engineering, simulation, operations and industrial quality control platforms.
- European certification program of equipment, infrastructures, platforms and big data services for their operation in the European Industrial Data Space.

Boost 4.0 started 1st January 2018 and with a duration of 3 years.

2.2.5.2 Main features

The goal of the Boost 4.0 Reference Architecture (RA) is to develop a reference architecture for Big Data in the manufacturing domain that achieves the following objectives:

1. Provides a common language for the various stakeholders.
2. Encourages adherence to common standards, specifications, and patterns.
3. Illustrates and improves understanding of the various Big Data components, processes, and systems.
4. Supports communication with other communities developing Reference Architectures for the manufacturing domain (for example RAMI4.0, IIRA).

The Boost 4.0 RA also serves as a tool to facilitate discussion of the requirements, design structures, and operations inherent in Big Data and is intended to facilitate the understanding of the operational intricacies in Big Data in context of the manufacturing domain.

[10] https://boost40.eu/

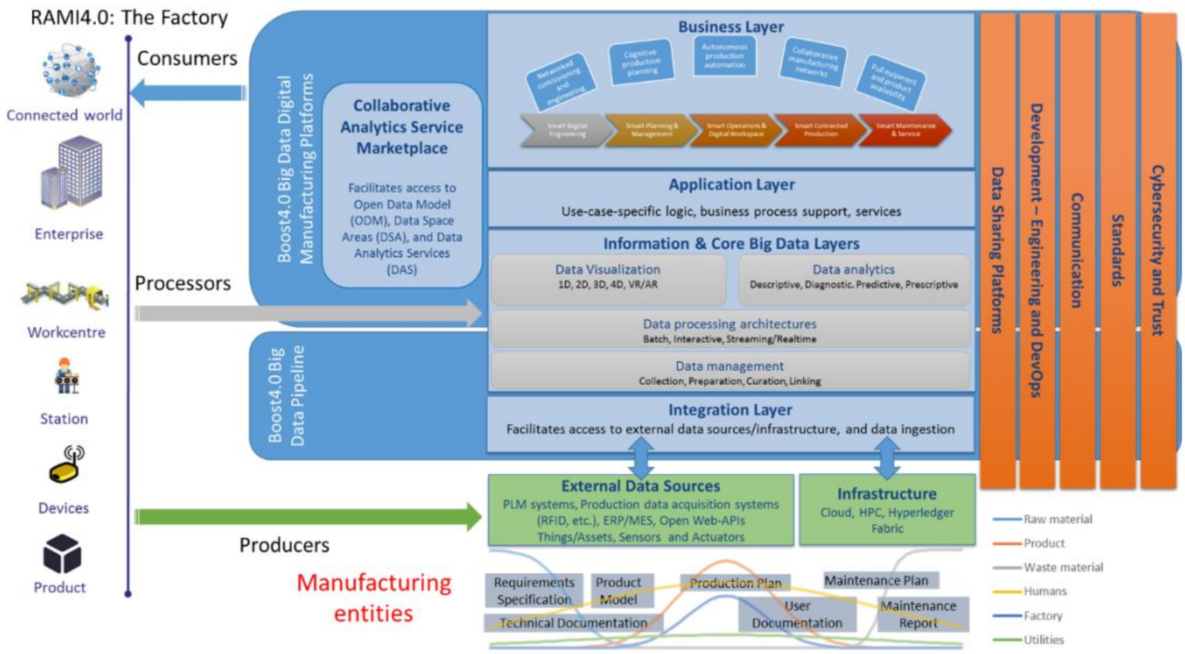

Figure 5. Boost 4.0 Reference Architecture

The core horizontal layers represent a collection of functionalities/components performing a specific role in the data processing chain, and are:

1. Integration layer, which facilitates management of external data sources and of infrastructure, as well as data ingestion.
2. Information and Core Big Data layers, consisting of components responsible for data management, processing, analytics and visualisation.
3. Application layer, which represents components implementing application logic that supports specific business functionalities and exposes the functionality of lower layers through appropriate services.
4. Business layer, which forms the overall manufacturing business solution in the Boost 4.0 five domains (networked commissioning & engineering, cognitive production planning, autonomous production automation, collaborative manufacturing networks, and full equipment & product availability) across five process life-cycle stages (Smart Digital Engineering, Smart Production Planning & Management, Smart Operations & Digital Workplace, Smart Connected Production, Smart Maintenance & Service).

Apart from the horizontal layers, there are a number of vertical cross-cutting aspects that affect all layers:

1. **Communication**: This aspect aims to provide the mechanisms and technologies for the reliable transmission, and reception of data between the layers of the Boost4.0 RA.
2. **Data sharing platforms**: This aspect considers the needs for allowing data providers to share their data as a commodity, covering specific data, for a predefined space of time, and with a guarantee of reversibility at the end of the contract.
3. **Development- Engineering and DevOps**: This aspect covers tool chains and frameworks that significantly increase productivity in terms of developing and deploying big data solutions.

4. **Standards**: This section will elaborate on the standards use within the Boost4.0 RA.
5. **Cybersecurity and Trust**: This aspect covers topics such as device and application registration, identity and access management, data governance, data protection, and so on.

2.2.5.3 Potential interest for i4Q

Several contributions coming from BOOST 4.0 can be of potential interest for i4Q. First, the BOOST 4.0 RA may constitute a basis for the i4Q Reference architecture. Further, the integration with European Industrial Data Spaces (IDSA), FIWARE and Big Data Europe initiatives may also be explored during i4Q. Finally, specific project results, such as technology artifacts, methods and other tools, may be reused, depending on requirements and use cases presented in i4Q.

2.2.6 Z-Fact0r

2.2.6.1 Overview

The Z-Fact0r project's duration was 42 months, from October 2016 until March 2020. This solution provides an implementation and design framework for systems in a blackboard computational architecture. This framework provides a different APIs to handle data flow and communications protocols in the system. The databases (persisting) are monitored and connected by a middleware, which routes all outbound and inbound data queries implementing a common database schema for all in the architecture. The data created by the components allow exploitation of the data for different purposes and further improvements of the system's outcome [11].

2.2.6.2 Main features

Z-Factor is a distributed system built on the philosophy of zero-defect manufacturing strategy. This system wants to become a standard solution. Therefore, this framework (**Figure *6***) is applicable to existing or new manufacturing lines.

The 5 points zero-defects strategies are[12]:

- **Z-Detect** (Targeting the early detection of the defect): This strategy is invoked when a defect is being generated. This consists of detecting any instability through the monitoring process or machining process anomalies by means of controlled variables.
- **Z-Predict** (Prediction of defect generation): This strategy is invoked when a defect is recognized during the Z-Detect stage. The basis of this system is to analyse the existing knowledge of the system that allows to learn new patterns (This knowledge can come from the physical layer or the system), drawing attention to discrepancies that cause operational and functional failures.

[11] https://www.z-fact0r.eu/overview
[12] https://www.z-fact0r.eu/z-fact0r-modules

* **Z-Prevent** (The prevention of defect generation and propagation in later stages of the production): This strategy is invoked by the z-predict stage. The prevention of strategy defects is based on quality control. This event handler oversees the recalibration of the production line as an error preventing measure. To that effect it will homogenize the system based on historical and current data, to preserve the system quality levels inside the acceptable limits.
* **Z-Repair** (Remanufacturing of the product using additive/subtractive techniques): This strategy is invoked by Z-Detect. It has the capability to automatically repair the concurrent defects without stopping the production flow.
* **Z-Manage** (Management of all strategies through event modelling, key performance indicators monitoring and real-time decision support): This strategy supervises and optimizes the system. To do so, it processes the data with the DSS (Decision Support System) tool and interconnects it with the MES (Manufacturing Execution Systems) systems.

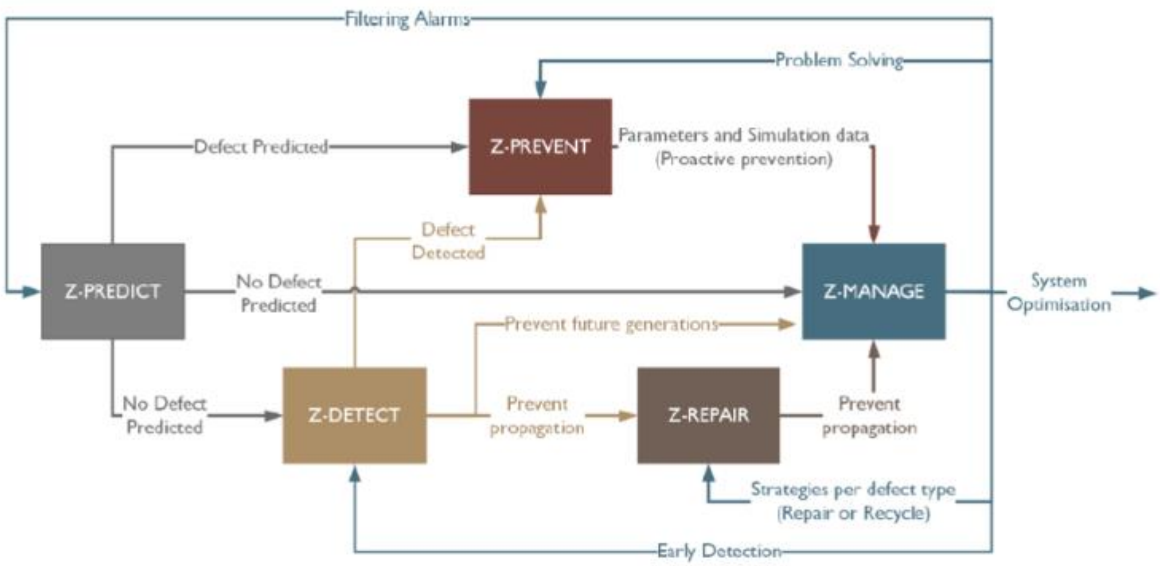

Figure 6. Z-Fact0r Architecture

Thanks to all the knowledge generated after those false positives that are generated in each Z-Factor strategy, they can filter each false alarm obtained. The methodology relies on two inspection systems – one on the Work-Station level and on the product level, as well as one online data gathering system and one online Defect Management system. In addition to the above, a Knowledge Management system provides intelligence and robustness to switch into the right strategy dynamically through the use of the three sub-systems.

2.2.6.3 Potential interest for i4Q

Z-Fact0r is a project that seeks to achieve zero-defect manufacturing through a novel ZDM platform. This project can help in i4Q solutions as an example of implementation and development of a framework based on zero-defect strategies. To do so, we can integrate the AI models, strategies, and technologies in the different i4Q solutions that seek zero-defects.

2.2.7 vf-OS

2.2.7.1 Overview

vf-OS[13] (virtual factory Open Operating System) began in October 2016 and completed in October 2019. This project enables the exploitation of technologies from Industry 4.0. This provides different services for different manufacturing and logistics processes, both within the organization and between the different supply providers. Vf-OS uses a Service Oriented Architecture (SOA) where there are different components to implement different individual solutions. All these inter-related components from the ecosystem publish a REST interface for the exchange of data, also using the messaging bus to be implemented within the project.

vf-OS is described as an Open Operating System for Virtual Factories (**Figure 7**) deployed in a cloud platform. This platform works as an application marketplace, offering services to integrate into manufacturing and logistics processes.

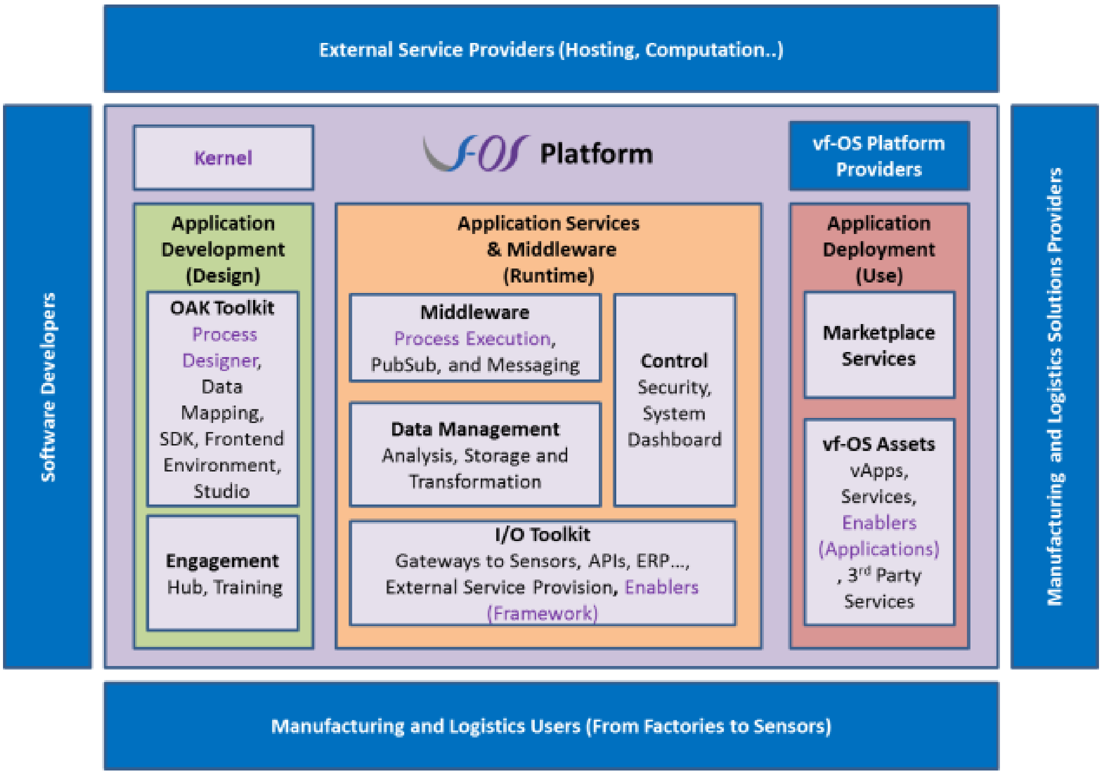

Figure 7. vf-Os Architecture

2.2.7.2 Main features

The main vf-OS features are:

- **Virtual Factory System Kernel:** The vf-OS kernel is one of the most important parts of the operating system. It provides the runtime for the processes and applications using a set

[13] https://www.vf-os.eu/

of vf-Os libraries, known as kernel, in the most optimal way. The kernel libraries implement the basic functions of the operating system.

- **Virtual Factory Device Drivers and Open APIs:** This is a set of modules connected to virtual images of vf-Os with a Plug-and-Play mechanism to allow access to the system without interruptions. Thanks to open APIs it can securely integrate bridges between manufacturing and vf-Os applications, allowing to access resources of the factory.
- **Virtual Factory Middleware and Databus:** This is a set of modules and smart objects-based data storage cloud (or on premise). If there are any problems with the cloud-based data warehouse, the accessibility of the data would be provided by the sensors. Thanks to this, problems or failures of the system are avoided.
- **Open Application Development Kit:** It is a toolkit for the development of targeted applications for the community. They allow it to run in vf-Os and cover all industrial sectors and specific scenarios. It also allows external companies to develop their own specific or specialized applications and integrate them within the vf-Os Platform.
- **Cloud Manufacturing Framework:** It is a new Platform with different commercial functionalities, all included in the vf-Os market and that allows them to be monetized. Furthermore, you have the ability to publish or buy manufacturing applications from external companies, creating a business opportunity.
- **Virtual Factory Components:** Vf-Os provides a development kit with applications and methodologies to develop a modular component. Thanks to this, we can easily integrate it into the system and with other developed technologies in factories or other projects without generating errors or interruptions in the supply chain.

These characteristics are based on the following concepts:

- **Open Access:** vf-OS and all its components are, by default, open source, which allows software developers and service providers to improve the vf-OS components and interact with the Virtual Factory Platform (vf-OAK) through the Open Applications Development Kit.
- **Sustainable Marketplace and App Store:** vf-OS uses the same approach used by mobile application markets such as Google Play or Apple Store. It has a virtual store based on applications focused on the manufacturing sector.
- **Joint Exploitation of Project Partners:** Thanks to the development of different projects and the use of cloud platforms, different partners can develop together many components and ensure the sustainability of the project results.

2.2.7.3 Potential interest for i4Q

Vf-Os present an environment focused factory, creating a marketplace to buy or sell such applications. It gives a business opportunity for external companies, but it also provides generic applications that can be specialized in zero-defect applications, pushing forward the concept of a smart, fully digitalized factory, depending on the characteristics and needs of the factories. This can be interesting as a basis for the distribution and connection of the different i4Q Solutions.

2.2.8 C2NET

2.2.8.1 Overview

The C2NET[14] project began in October 2015 and completed in December 2017. This Project is a cloud-enabled toolset for supporting the SMEs supply network optimization of manufacturing and logistic assets. This asset is based on demand, delivery and production plans. This project provided a scalable real-time software, architecture and platforms to allow the supply network partners to share or store products, logistics or process data, collaborative computation of production plans to optimize the manufacturing assets, etc.

C2NET is designed to support the storage of IoT environments, as well as information from legacy systems, so that it can collect data and detect patterns in real time. To make this work, C2NET provides a number of cloud-based tools that support collaborative demand-driven optimisation of the supply network of logistics and manufacturing assets. To make this work, one of the objectives of the C2NET architecture is to provide real-time scalability with interoperability in mind.

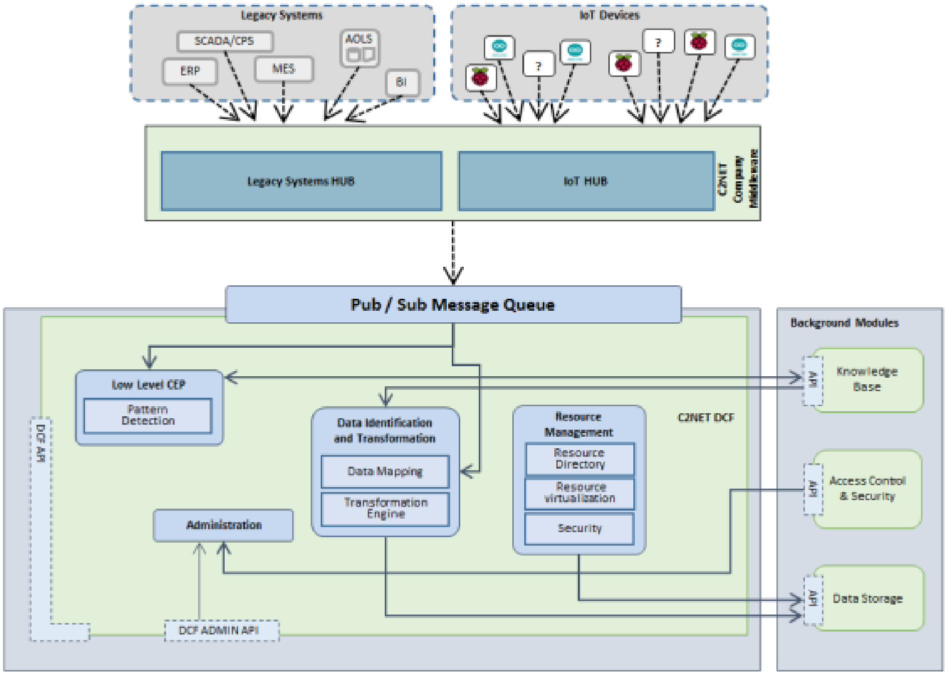

Figure 8. C2Net Architecture

2.2.8.2 Main features

The C2NET Project generates a Cloud Architecture composed by:

- **C2NET DCF** (The Data Collection Framework): This framework provides hardware devices for IoT and software components based on ongoing data collection from supply network resources. This allows the real-time data collection of all information from different

[14] http://c2net-project.eu/

physical devices or chain enterprise systems, thus providing the C2NET platform a complete view of the network.

- **C2NET OPT** (The optimizer): The optimization of logistics and manufacturing assets to support manufacturing networks by collaborative computation of production plans. This gives advanced optimization algorithms for collaborative computation of delivery, replenishment, and production plans focused on optimizing the use of logistics and manufacturing assets of the supply network.
- **C2NET COT** (The collaboration Tools): It is the set of tools that oversees and manages the agility of the collaborative process. It includes a concrete solution to facilitate the diagnostic of collaborative chain values coming from any source of divergence. These tools will be able to support the adaptation of the stakeholders by implementing reaction mechanisms based on optimization algorithms.
- **C2NET CPL** (The Cloud Platform): It contains a cloud platform that includes the different modules needed to generate a collaborative working environment with network partners. It provides access to information collected from distributed and heterogeneous sources to create local and global production plans to optimize the processes. To do so, it uses the data received from suppliers, manufacturers, and customers. As a result, it allows a faster and more efficient decision-making process, which is fundamental due to high competition, market changes and customization requirements. The C2NET Cloud platform allows collaborative production. To this end, it focuses on obtaining real-time information. Thanks to this, it makes supply and distribution decisions for the different customers or their production plans, all calculated based on real time information coming from real resources.

2.2.8.3 Potential interest for i4Q

The C2NET project provides a cloud-enabled toolset for supporting the SMEs supply network optimization of manufacturing and logistic assets based on collaborative demand, production, and delivery plans. Thanks to the collaboration tools and Cloud platform, i4Q can exploit this architecture to improve access to all its proposed solutions. On the other hand, the expertise provided by C2NET DCF, defined a software for IoT devices and allow real-time data collection (One of the most important bases of i4Q solutions).

2.2.9 IKERLAN KONNEKT

2.2.9.1 Overview

IKERLAN KONNEKT[15] is a family of digitization solutions that adapts to the specific needs of each digitalization strategy. It covers all the necessary elements to be able to offer a Digital Platform, integrating elements of own development and third-party applications.

[15] https://www.ikerlan.es/en/ikerlankonnekt

2.2.9.2 *Main features*

Figure 9 shows all the stages involved in the IoT and IIoT workflow. Below the workflow operations, three vertical domains appear: transport, energy and industry 4.0. Each vertical domain has different use cases that can apply on top of each workflow operation. Once defined the different use cases and how they map to each operation, IKERLAN KONNEKT defines the necessary elements to integrate and deploy a Digital Platform.

The different stages go from left to right, starting with the data extraction, through hardware components and sensors, and finishing with the data processing in the cloud. On each stage, IKERLAN KONNEKT proposes different technologies that cover each operation and how they integrate into a Digital Platform.

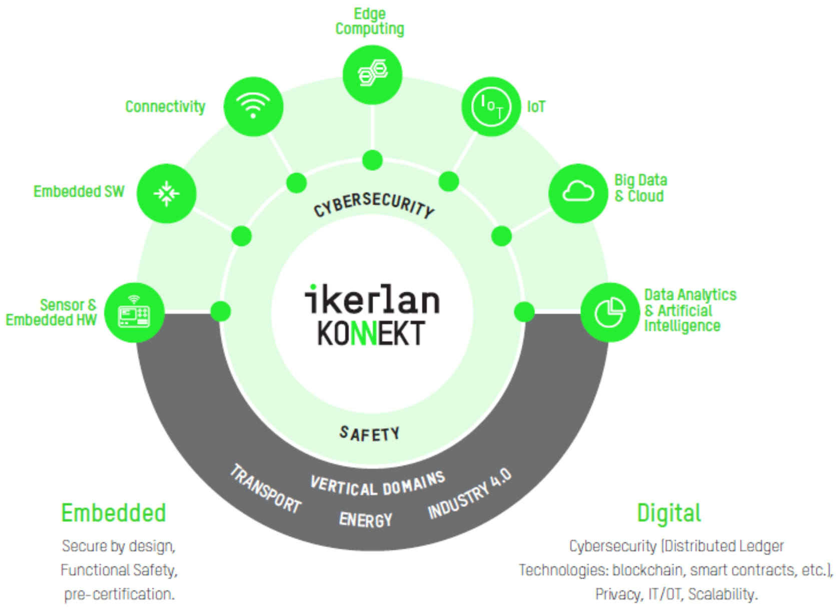

Figure 9. IKERLAN KONNEKT infographic

IKERLAN KONNEKT has been designed with three non-functional requirements in mind:

- **Interoperability**: it is designed to be related to other products and integrated into the processes and digital platforms of clients, guaranteeing interoperability and scalability.
- **Scalability**: it is designed to respond to fleets or parks of growing connected equipment, maintaining the quality and the capacity of management and storage of the data derived from them.
- **OT/IT CONVERGENCE**: it can optimally integrate IT technologies, oriented to data computing, with OT technologies, oriented to the monitoring and control of industrial processes and equipment.

2.2.9.3 *Potential interest for i4Q*

IKERLAN KONNEKT can be exploited in i4Q by integrating some of IKERLAN KONNEKT technologies into i4Q components. There has to be an analysis of the requirements and use cases presented in i4Q. After the analysis, there can be a proposal on how IKERLAN KONNEKT can boost the development and integration of i4Q components.

2.3 i4Q Vision and Positioning

i4Q Project will develop a set of Solutions to improve the quality of manufactured products aiming at zero-defect manufacturing, therefore pushing forward the concept of a smart, fully digitized factory. One of the key concepts in i4Q is that having (large) amounts of data (from the shop floor, form the design process, from product testing), is not enough to achieve the actual benefits which smart factories aim to achieve. In order to achieve the objectives, which are described below, i4Q adopts a straightforward yet well-tested and effective approach which includes a needs capturing part, a fundamental design phase to produce a reference architecture and framework, a build phase which delivers the actual tools and technologies used in the framework, a key evaluation phase to ensure real-world applicability of the results and impact generation activities centred around dissemination and exploitation actions and tasks.

The project Vision Consensus task (lead: CERTH, M01-M03) provides a balanced guide document as a deliverable, which will act as a reference for the project and will be used by all partners to stay focused on the main ideas and goals of the project. The document will also be used internally to keep the performed tasks in synchronisation with the overall idea of the project. It may also be used by the partners as a source for documents, deliverables and presentations to third parties to get an early overview of the project. In addition, this document will include an initial risk table, upgraded from the DoA, which itemises general inherent risks of innovation activities.

The i4Q objectives to create the project results and outcomes are stated below. To ensure focus, there is a 1:1 relationship between each objective and work package number.

O1: To develop and share among the different consortium partners and other stakeholders the i4Q Project Vision, establish the state of the art in terms of technologies for quality in manufacturing, and to set the requirements driving the creation of i4Q Solutions. (WP1)

O2: To design the i4Q Framework and deliver the Reference Architecture built on key digital models and ontologies for smart manufacturing and devised using multiple perspectives, related to business, usage, functional and implementation viewpoints. (WP2)

O3: To build the i4Q Manufacturing Data Quality, providing methodologies, tools and infrastructure to ensure the necessary data quality to enable operational intelligence and improve data analysis results effectiveness. (WP3)

O4: To build the i4Q Manufacturing Data Analytics, a set of management tools for cloud/edge lifecycle of manufacturing related artificial intelligence models. (WP4)

O5: To build the i4Q Rapid Manufacturing Line Qualification and Reconfiguration, a set of new and improved strategies and methods for process qualification as well as process reconfiguration and optimisation using existing manufacturing data and machine learning algorithms. (WP5)

O6: To test and validate the i4Q Solutions in 6 use cases, covering different manufacturing perspectives (industrial equipment manufacturers, parts and components manufacturers and final products manufacturers) and industrial sectors (metal, plastic, wood and ceramics). (WP6)

O7: To disseminate the i4Q Solutions, providing outreach of the project activity and results, paving the way for a broad adoption of i4Q Solutions in the industry, offering benefits for final users. To create the i4Q standards, compliant with existent and evolving ICT and CE standards, facilitating regulation and certification. (WP7)

O8: To facilitate technology uptake by the i4Q start-up company that is being created and long-term adoption of the i4Q Solutions by the industry. (WP8)

O9: To properly manage the project for guaranteeing that the project objectives are met by ensuring the successful completion of the project on-resource, on-quality and on time. (WP9)

3. Relevant Initiatives and Reference Architectures

In the context of the Industrial Internet, also known as Industry 4.0, Reference Architectures (RA) are fundamental assets, as they serve as the link between system architects and the different participants in the manufacturing chain as plant personnel, engineers, business consultants, etc. The final objective of this collaborative work is to find the convergence between the OT and the IT to match the expected business outcomes.

In this area of research, there exist several working groups putting their efforts on providing different reference models, approaching the topic from different points of view and perspectives. In this regard, two consortia: i) IIC (Industrial Internet Consortium) and ii) Working Group for Industry 4.0, are providing promising results in terms of recommendations and guidelines. The first one proposes the Industrial Internet Reference Architecture (IIRA) and the second one presents the Reference Architecture Model for Industry 4.0 (RAMI 4.0). Both reference architectures, that will be presented in more detail in the following chapters, are nowadays main sources of information when Industrial Internet Systems (IISs) are to be designed and developed. Common objective of both approaches is to provide a collaborative and data-driven environment, capable to transform the processes efficiency in the industrial domain.

To support industries digitisation, the references models presented use the IoT, services, personnel, and machines as central components to decompose functions, services, and processes into more intuitive, simpler, and functional subprocesses. In this manner, in the next chapters it will be described which architectural patterns are followed by the reference models, how the information is managed among the different layers of the architecture, how is the communication between the different layers, etc. In addition to the reference architectures presented above, in subsequent chapters the Digital Factory Alliance, a manufacturing-oriented Service Reference Framework align with the RAMI 4.0 that arises from EU projects, and BDVA Reference Architecture, a reference framework made by the European BDVA (Big Data Value Association) that describes logical components of a generic big data system, will be presented.

Following the terminology defined in the ISO/IEC/IEEE 42010 (ISO, 2011), the importance of selecting the correct architectural framework to define an information technology system in an industrial environment resides on the fact that those systems are usually composed by a set of interconnected machines or industrial equipment, that can produce vast amounts of data. The correct definition of the information system will allow companies to gather, exchange, transmit and analyse all data generated during a manufacturing process, with the aim of improving its efficiency and performance, reducing the number of defects and failures during production phase. Consequently, to follow the recommendations coming from the experts' community is a good practise when architectural decisions have to be taken in consideration, in order to match all the stakeholders' expectations as much as possible.

3.1 IIC

The IIC[16], that stands for Industrial Internet Consortium, is a global not-for-profit partnership of industry, government and academia, founded in March 2014. It is composed by a set of members offering different profiles and perspectives, from small and large technology innovators, vertical market leaders, to researchers, universities and government organizations.

The IIC aims at bringing together the organizations and technologies necessary to accelerate the growth of the industrial internet by identifying, assembling, testing and promoting best practices. In this context, members work collaboratively to speed the commercial use of advanced technologies and also on giving the organisations the necessary guidance to strategically apply digital technologies and achieve digital transformation.

The IIC helps technology users, vendors, system integrators and researchers achieve tangible results as they seek to digitally transform across the enterprise through the realisation of multiple activities and programs.

IIC addresses concerns about IIoT across industries broadly, while RAMI4.0 (paragraph 3.3) focuses mainly on manufacturing in depth.

3.1.1 IIRA

The Industrial Internet Reference Architecture (IIRA) has been published by the Industrial Internet Consortium (IIC) in the document "The Industrial Internet of Things Volume G1: Reference Architecture" and contains architectural concepts, vocabulary, structures, patterns and a methodology for addressing design concerns. The document identifies the fundamental architecture constructs and specifies design issues, stakeholders, viewpoints, models and conditions of applicability defining a framework by adapting architectural approaches from the ISO/IEC/IEEE 42010-2011.

3.1.1.1 Overview

Essentially, the IIRA attempts to identify the most important and common architecture concerns. It then provides an architectural template and methodology that engineers can use to examine and resolve design issues. In addition, the template and methodology suggest ways of addressing the top concerns, allowing designers to glean insights by examining architecture patterns, helping Industrial Internet of Things (IIoT) system designers to avoid missing important architecture considerations and also help them to identify design gaps of missing important system functions or components.

IIRA represents an architectural template to categorize IIoT system requirements and design concrete architectures to address them. Using this common approach to architecture design, IIRA assists in obtaining a consistent architecture implementation across different use cases in various industrial sectors meeting unique system requirements.

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

The IIRA emphasizes interoperability and practical deployment of IoT technologies. It is high-level, yet quite detailed in terms of the specification of the stakeholders and the components that comprise IIRA compliant IoT systems. However, it is not a proper vehicle for specifying the low-level implementation details of an IoT systems. Rather, it is mainly used for specifying structuring principles of IoT systems, as well as for communicating concepts and boosting stakeholders' collaboration.

3.1.1.2 Main features

The core of the IIRA methodology lies in a set of system conceptualization tools called viewpoints that enable architects and engineers to identify and resolve key design issues. Thus, the IIRA design starts with defining the shapes and forms of an Industrial Internet of Things Architecture by starting with the viewpoints of the stakeholders. These IIRA viewpoints are arranged in a particular order to reflect the pattern of interactions that occurs between them, because the decisions from a higher-level viewpoint impose requirements on the viewpoints below it.

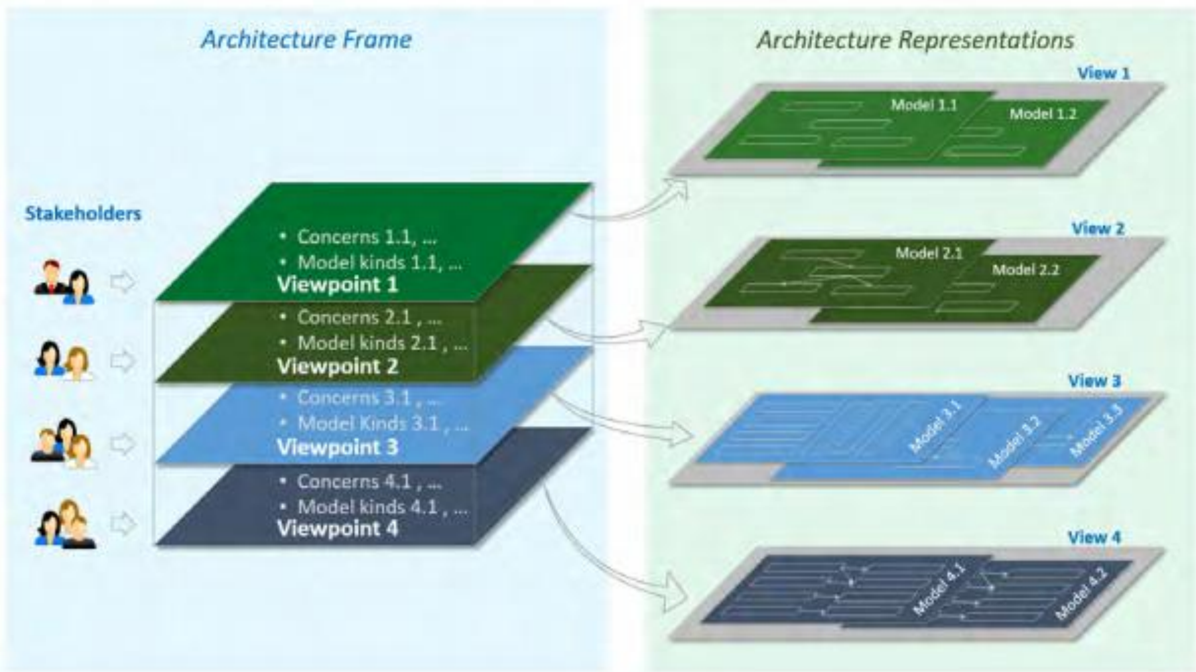

Figure 10. IIRA Architecture Framework (IIC, 2019)

In this sense, the IIRA is a layered model that takes into consideration four different viewpoints (business, usage, functional, and implementation). It focuses on the capabilities from the perspective of the software and their business processes (IIC, 2019):

- **The business viewpoint**, which identifies the stakeholders that engage in the development, deployment and operation of an IoT system, including their business vision and objectives. The business viewpoint takes into account the overall business and regulatory context, in which the IoT system operates.
- **The usage viewpoint,** which specifies the actual usage of the IoT system. This usage is illustrated based on sequences of activities that may be performed by human actors and/or logical components (e.g., system or system components).

- **The functional viewpoint,** which specifies the functionalities of the IoT system. To this end, it illustrates the functional components that comprise an IoT system along with their interfaces and interactions. It also presents any interactions with external logical modules (e.g., external subsystems).
- **The implementation viewpoint,** which comprises the implementation technologies that are used to implement the functional components, along with information about their lifecycle and the realization of the communication between them.

While all four viewpoints are important for the realization of an IoT system, it is the functional viewpoint that is the most important when it comes to engineering and implementing an IoT system. In particular, the IIRA functional viewpoint specifies a number of individual/distinct functionalities, which are called functional domains. Hence, any IoT system can be decomposed into "functional domains", which are important building blocks that are applicable across different vertical domains and applications. In particular, the IIRA decomposes a typical IoT/IIoT system into five functional domains, namely a control domain, an operations domain, an information domain, an application domain and a business domain as outlined in **Figure *11***.

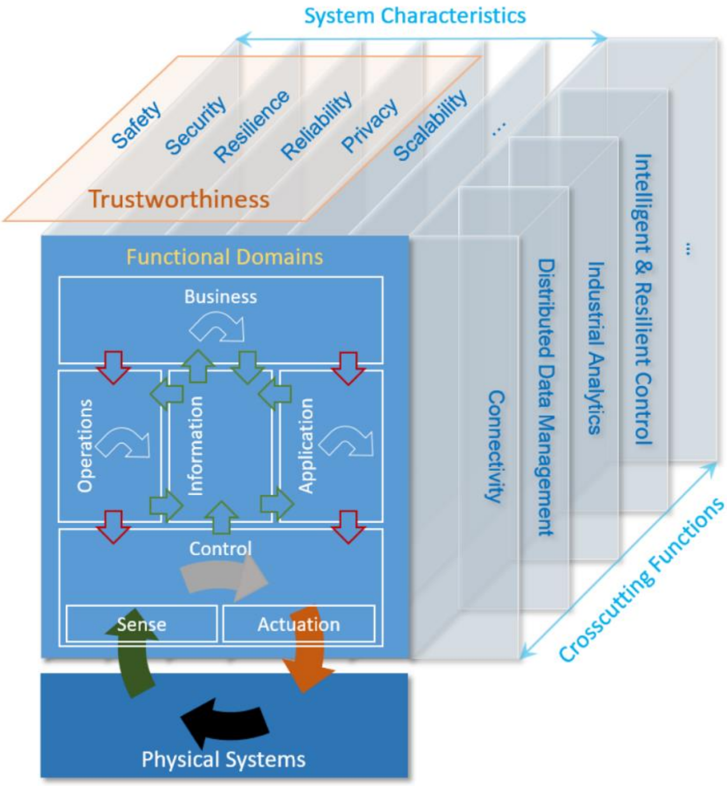

Figure 11. Functional Domains, Cross-Cutting Functions and System Characteristics as specified in the IIRA (IIC, 2019)

Note that **Figure *11*** illustrates also some cross-cutting functions, i.e. functions that are domain agnostic. These include connectivity, distributed data management, industrial analytics and intelligent control. For example, connectivity ensures that all systems and devices (regardless of their functionality) can connect to each other on the shopfloor. Likewise, data acquired from the various systems and devices needs to be appropriately routed to different applications across all available functional domains, which illustrates the importance of the distributed data management functionalities.

3.1.1.3 Potential interest for i4Q

IIRA aims at a comprehensive model of the industrial internet, independent of specific domains and industries. The wide scope results in a broad coverage of topics being able to make compliant with various IIoT architectures. On the other side, IIRA concrete implementation guidelines are only partly provided. Furthermore, IIRA lacks an explicit set of addressed concerns; this results in a certain vagueness of requirements for IIoT implementations. The three layers approach will guide the conceptual definition of the i4Q RA, while specific details to guide implementation activities will be provided in the second version. The IIRA Layered Databus Architecture Pattern should be taking into account for implementing a data-driven approach.

3.1.2 OpenFog

The OpenFog Consortium is a public-private initiative, which was founded in 2015 and has many similarities with the IIC. The founding members of the OpenFog Consortium included Microsoft, Dell, Cisco, ARM, Intel and Princeton EDGE Lab and were aiming at solving problems that occurred around development and deployment of edge computing and cloud computing, as well as technical difficulties around latency and controlling assets at the edge.

The OpenFog RA is intended to help engineers, architects, and business leaders to understand their specific requirements and how fog nodes can be applied to a given scenario. The overall goal is to increase the market segments (use cases) for fog computing, and its business value. The OpenFog consortium aim to create test-beds to adapt the high-level architecture to the identified market segments.

In January 2019, the IIC and the OpenFog Consortium announced that they have combined the two largest and most influential international consortia in Industrial IoT, fog and edge computing into a more extensive IIC. The goal of the new IIC is to drive the momentum of the industrial internet, incorporating the development and promotion of industry guidance and best practices for fog and edge computing

3.1.2.1 Overview

The OpenFog RA is driven by a set of core principles, that are defined as the Pillars of the OpenFog RA (see **Figure *12***). These pillars represent the key attributes that a system needs to follow the definition of the OpenFog definition of a horizontal, system-level architecture that provides the distribution of computing, storage, control and networking functions closer to the data source (users, things, etc.) along the cloud-to-thing continuum (OpenFog, 2017).

Figure 12. Pillars of OpenFog (OpenFog, 2017)

- **Security Pillar:** Security is one of the important topics in any IoT solution. This pillar describes all of the mechanisms that can be applied to make a fog node secure, starting from the silicon level up to the software application. There is not a single solution for each fog node.
- **Scalability Pillar:** This pillar addresses the dynamic technical and business needs behind fog deployments. The scalability targets fog node internals (through the addition of hard- or software) as well as the externals, where fog networks should be scalable through addition of new fog nodes to assist in heavy load operation or storage and network connectivity, to enlarge the overall fog network.
- **Openness Pillar:** Openness is essential for the success of ubiquitous fog computing solutions. Proprietary or vendor lock-in can have as a result that only limited suppliers can be available, and thus negatively influence system costs, quality and innovation. Openness is also an essential feature for interoperability between different systems.
- **Autonomy Pillar:** Autonomy enables fog nodes to continue to provide the designated functionality even during external service failures. Decision making will be based on all levels of the system, including near to the device. Autonomy at the edge level means autonomy and intelligence present at the local devices.
- **Programmability Pillar:** Programmability enables to deploy different applications to the fog nodes and the possibility to modify the system on software as well as on the hardware layers.
- **Reliability, Availability, and Serviceability (RAS) Pillar:** Reliability, availability and serviceability (RAS) are of vital importance. These topics refer to hardware, software as the applications running on the node. Reliability defines that the fog node will continue to deliver its designated functionality under normal as well as unexpected behaviour. Availability defines continuous operation (management, control, orchestration, etc.) of the system, which is quite often measured in uptime. Finally, serviceability relates to

providing the correct operation to the system, meaning the application does what it is supposed to do.

- **Agility Pillar:** The agility pillar addresses business operational decisions for an OpenFog RA deployment. Agility focuses on transforming data into information that is needed for the actions within the system. It also deals with the highly dynamic nature of fog deployments and the need to respond quickly to changes inside the network and the deployment, like new data or new requests.
- **Hierarchy Pillar:** Computational and system hierarchy is not required for all OpenFog architectures, but it is still expressed in most deployments. Many deployments have a different hierarchy, varying from cloud level to shopfloor level. The hierarchy is completely dependent on the application where the fog nodes will be deployed but is of importance to building up the system.

3.1.2.2 Main features

Besides viewpoints, two other concepts are used to describe the OpenFog RA, namely: *views* and *perspectives*. A view is defined as a representation of one or more structural aspects of the architecture. Consecutively, a perspective is identified as a cross-cutting concern of the architecture. An overview of the OpenFog RA, distinguished in views and perspectives is depicted in **Figure** *13*. The grey vertical bars represent the perspectives, whereas the horizontal coloured bars include the views.

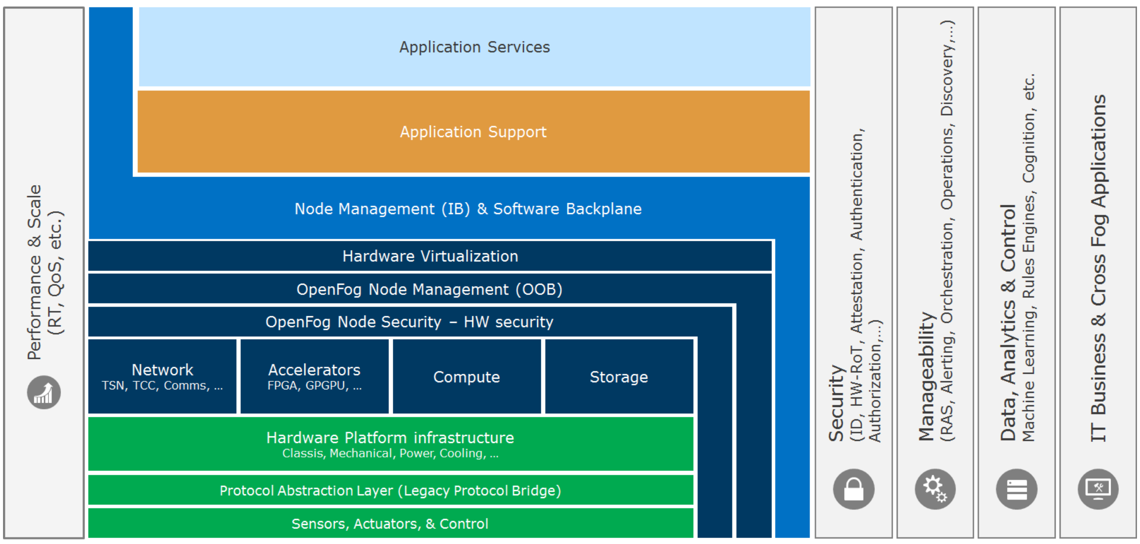

Figure 13. OpenFog Architecture Description with Perspectives (OpenFog, 2017)

Crosscutting refers to functionalities/capabilities that are applied across different architectural layers. As can be seen in **Figure** *13*, there are five cross-cutting perspectives identified for the OpenFog RA.

- **Performance and Scale Perspective:** Low latency is one of the driving reasons to adopt fog architectures. There are multiple requirements and design considerations across multiple stakeholders to ensure this is satisfied. This includes time critical computing, time sensitive networking, network time protocols, etc. It is a cross cutting concern because it has system and deployment scenario impacts.

- **Security Perspective:** End-to-end security is critical to the success of all fog computing deployment scenarios. If the underlying silicon is secure, but the upper layer software has security issues (and vice versa) the solution is not secure. Data integrity is a special aspect of security for devices that currently lack adequate security. This includes intentional and unintentional corruption.
- **Manageability Perspective:** Managing all aspects of fog deployments, which include RAS, DevOps, etc., is a critical aspect across all layers of a fog computing hierarchy.
- **Data, Analytics and Control Perspective:** The ability for fog nodes to be autonomous requires localized data analytics coupled with control. The actuation/control needs to occur at the correct tier or location in the hierarchy as dictated by the given scenario. It is not always at the physical edge, but may be at a higher tier.
- **IT Business and Cross-fog Applications Perspective:** In a multi-vendor ecosystem applications need the ability to migrate and properly operate at any level of a fog deployment's hierarchy. Applications should be able to span all levels of a deployment to maximize their value.

As mentioned before, next to the perspectives, the OpenFog RA description is a composite of different views. Multiple layers of the OpenFog RA are encapsulated in the different identified views.

- **Node View:** The node view is the lowest level view that is utilized inside the architectural description; it is represented in the bottom two layers, which includes the Protocol Abstraction Layer and Sensors, Actuators, and Control. Stakeholders involved in this viewpoint (and subsequently this view) are mainly the system on chip designers, silicon manufacturers, firmware architects and system architects, thus focusing on the lowest design level of the actual fog node. This view describes the most important aspects for a fog node design, before it could be included into a (fog) computing network within a factory.
- **System Architecture View:** The system view of the OpenFog RA is composed of one or more node views combined with other components to create a platform. It is represented in the middle layers shown in the architecture description, which include Hardware Virtualization down through the Hardware Platform Infrastructure. The stakeholders involved in this view are mainly system architects, hardware OEMs, and platform manufacturers. This view includes the node view, but although only a single node view is included, but the system architecture must be able to support multiple nodes. Therefore, the performance and scale perspective are included to highlight that multiple nodes can be supported.
- **Software Architecture View:** The software architecture view is composed of software running on a platform that consists of one or more node views in combination with other components to create a system addressing a given scenario. The software of the fog node can be separated into three layers that sit on top of the platform hardware layer: Application Services, Application Support, Node Management and Software Backplane. The stakeholders involved in this view are mainly system integrators, software architects, solution designers, and application developers of a fog computing environment.

3.1.2.3 *Potential interest for i4Q*

The OpenFog RA defines the required infrastructure to enable building Fog as a Service (FaaS) to address certain classes of business challenges. The OpenFog RA describes a generic fog platform that is designed to be applicable to any vertical market or application. It provides business value for IoT applications that require real-time decision making, low latency, improved security, and are network constrained. The "horizontal" system-level approach that characterizes fog computing will be an input to the definition of the i4Q RA to drive the continuous distribution of computing resources and services, data storage, control, and networking capabilities over the infrastructure connecting the cloud to the edge. This approach will help to define a distributed network architecture that connects the cloud to the various compute nodes at the "edge" of the network.

3.2 IoT Reference Architecture ISO IEC 30141

3.2.1 Overview

ISO / IEC 30141:2018 standard for Internet of Things (IoT) - Reference Architecture[17], provides a common vocabulary to develop and design IoT applications. This standard is linked to the progress and digital transformation, providing a good practice guide for this sector along with common vocabulary and reusable designs.

This ISO describes a generic IoT system characteristic, a Conceptual Model (describing the key concepts characterizing an IoT system), a Reference Model (providing the overall structure of the elements of the architecture) and a number of architectural views aligned with the architecture descriptions defined in ISO 42010[18] (**Figure *14***). The objective is to provide a greater understanding of IoT systems to the users of these systems (from manufacturers to end users).

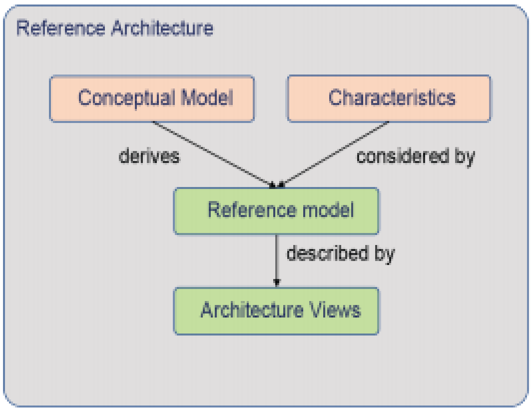

Figure 14. IoT RA structure (ISO 30141:2018)

[17] https://www.iso.org/standard/65695.html

[18] https://www.iso.org/obp/ui/#iso:std:iso-iec-ieee:42010:ed-1:v1:en

3.2.2 Main features

The ISO / IEC 30141:2018 standard defines the characteristics necessary for the implementation of IoT systems. For this implementation, 3 blocks are defined, that can be functional, such as connectivity, or non-functional, such as availability and compliance.

- **IoT System Reliability Features**: Focuses on analysing system trust focusing on security, privacy, reliability, and protection against environmental disruptions, errors, or attacks.
- **Architecture characteristics of the IoT system**: It focuses on analysing the architecture of the system focusing on features such as scalability, interconnection, modularity, or heterogeneity.
- **Functional characteristics of the IoT system**: It focuses on defining the functionalities of the system, focusing on network specifications, data characteristics, flexibility, or services they offer.

3.2.3 Potential interest for i4Q

Thanks to this standard, we will escalate security in our devices by increasing privacy and avoiding possible cyberattacks. Any company wishing to deploy IoT devices, must be based on an architecture referenced to ensure network security. On the other hand, it provides us with a model to follow when defining an architecture for IoT systems (scalability, modularity, etc.) within i4Q solutions. In addition, system specifications are defined.

3.3 RAMI 4.0

The Reference Architectural Model Industrie 4.0 (RAMI 4.0) was developed by the Plattform Industrie 4.0 in 2015 and focuses on the IoT and Cyber-Physical Systems (CPS) in the industrial manufacturing domain. RAMI 4.0 is one of the prominent reference architectures for Industry 4.0 use. The first version of the reference architecture appeared in April 2015. This was almost at the same time when the Industrial Internet Consortium (IIC) promoted the Industrial Internet Reference Architecture (IIRA). The goal of both architectures is to define a uniform framework for advanced industrial information and communication technologies as well as automation and production technologies. At the same time both standards belong to the category of open standards and aim to support business models and innovative solutions, providing a well-defined vocabulary and structure.

3.3.1 Overview

Recently, RAMI 4.0 has been successfully recognized in national and international standardization committees and cooperations as DIN standard (DIN SPEC 91345:2016) and international pre-standard (IEC PAS 63088:2017).

RAMI4.0 is a three-dimensional model, which describes the Industrie 4.0 space and organizes the lifecycle/value streams and the manufacturing hierarchy levels across the six layers of the IT representation of Industry 4.0. It outlines a comprehensive view of manufacturing related implications to any IoT landscape. The primary topic, the integration of the physical asset and its digital representation, is proposed relying on a common representation called the Asset Administration Shell (AAS).

Analysis of RAMI 4.0 according to various criteria:

1. **Industrial context:** RAMI 4.0 has a strong industrial focus, managing the entire value chains along with product lifecycles. Thus, RAMI 4.0 is fully applicable for manufacturing.
2. **Structuring capabilities:** The architecture is very suitable for structuring technologies as it offers a common structure and language for the uniform description and specification of concrete system architectures. There are helpful tools, as e.g. the XML-based visualization tool for browser, that makes it possible to use the RAMI 4.0 for Industrie4.0-based modelling.
3. **Compliance:** Though each architecture was developed independently with different objectives and scopes, they share very common aspects and approaches. RAMI 4.0 compliance has been analysed with respect to IIRA in the Joint Whitepaper "Architecture Alignment and Interoperability" of the IIC and Plattform Industrie 4.0 (IIC:WHT:IN3:V1.0:PB:20171205) (IIC, 2017).
4. **IIOT:** Though RAMI 4.0 does not specifically address the topic of IoT as e.g. *ISO/IEC 30141*:2018 Internet of Things (loT) - Reference Architecture, a short analysis of both architectures shows compatibility (based on current work of ISO TC 184/ IEC TC 65 JWG 21 *Smart manufacturing reference model(s))*.
5. **Interoperability:** Interoperability is one of the major topics in RAMI 4.0. This can be understood both, firstly, as interoperability across and/or among the layers and, secondly, it can cover the aspects of interoperability inside each layer.
6. **B2B:** The Industry 4.0 Component and the Asset Administration Shell are key features of RAMI 4.0 that help to reflect a physical object across RAMI 4.0 layers into the informative world. The interoperability of I4.0 Components is greatly dependant on the properties that support the adequate description of products and services in the B2B area.

3.3.2 Main features

Reference models, such as the Reference Architecture Model for Industry 4.0 (RAMI 4.0), provide a solution-neutral reference architectural model for applications that make use of Internet of Things (IoT), big data analytics, and other technologies advancements in manufacturing processes, what is known as smart manufacturing, intelligent manufacturing, or simply Industry 4.0. One of the main objectives once adopted is to be able to communicate the scope and design of the system, to foster collaboration and integration with other relevant initiatives by framing the developed concepts and technologies in a common model.

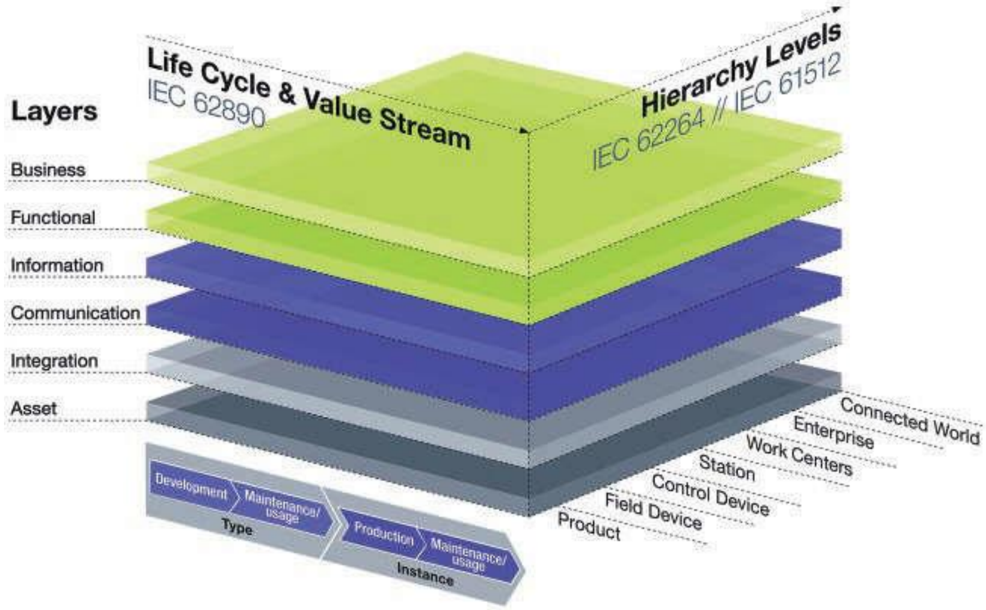

Figure 15. The three dimensions of the RAMI 4.0 (Source: Platform I4.0 And ZVEI)

The three-dimensional matrix can be used to position standards and describe use-cases. It addresses integration within and between factories, end-to-end engineering and human value-stream orchestration. This model is complemented by the Industry 4.0 components and both have been described in (DINSPEC91345:2016-04, 2016).

In RAMI4.0, each component consists of six layers. Starting with the lowest layer, the structure consists of asset, integration, communication, information, functional and business and represents a layered IT system structure, as shown in the figure below[19].

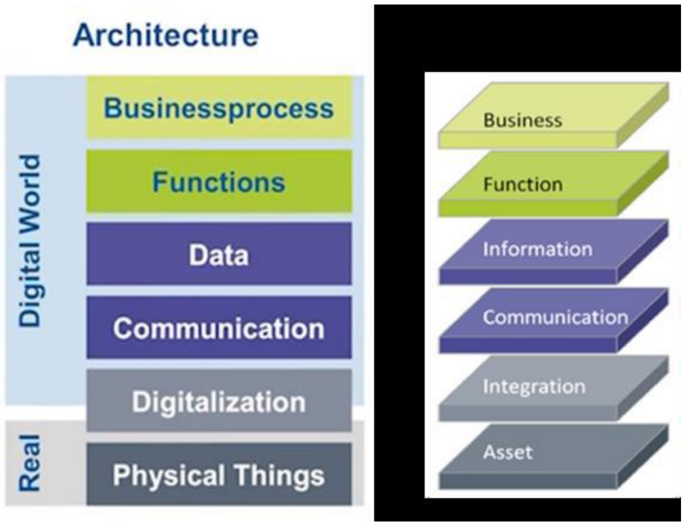

Figure 16. The IT Layers of RAMI 4.0

The function of each layer is:

[19] https://ec.europa.eu/futurium/en/system/files/ged/a2-schweichhart-reference_architectural_model_industrie_4.0_rami_4.0.pd

- The asset layer describes the physical components of a system, for example production equipment, product part, sensors, documents, as well as humans. For every asset represented in this layer there must be a virtual representation in the above layers. Among the physical assets, this layer includes the digital interface with humans and the relationship to elements in the integration layer.
- The integration layer deals with easy to process information content and can be considered as a bridge between the real and the IT world. It contains all elements associated with the IT, including field buses, HMIs, necessary to implement a function, as well as the properties and process related functions required to use an asset in the intended way and generates events based on the acquired information.
- The communication layer is responsible for the standardized communication between integration and information layer. Therefore, it performs transmission of data and files and standardizes the communication from the Integration Layer, providing uniform data formats, protocols and interfaces in the direction of the Information Layer. It also provides services to control the integration layer.
- The information layer holds the necessary data in a structured and integrated form and provides the interfaces to access this structured data from the functional layer. It is responsible for processing, integrating and persisting the data and events, as well as for describing the data related to the technical functionality of an asset. It can be considered the run-time environment for Complex Event Processing (CEP) where rule-based (pre-) processing of events takes place, data APIs and data persistence mechanisms. So, events are received from the communication layer, transformed and forwarded accordingly.
- The functional layer describes the logical and technical functions of an asset providing a digital description of its functions and a platform for horizontal integration of various functions; it also describes the business model mapping, business processes which can be adjusted based on inputs from the functional layer, providing models with runtime data of processes, functions and applications.
- The business layer is in charge of orchestrating the services provided by the functional layer. It maps the services to the business (domain) models and the business process models. It also models the business rules, legal and regulatory constraints of the system. The processes to ensure of the economy are located on this level.

Asset Administration Shell

The Asset Administration Shell (AAS) is a standard model aiming to create a bridge between the real world and the IoT world integrating assets into the world of information.

An asset is everything that can be connected for implementing an Industrie4.0 solution (i.e., machinery, parts, supply material, documents, contracts, etc.). The AAS also defines the data models for the exchange of information between partners in the value chain (see ***Figure 17***) and a package file format (the Asset Administration Shell Package, AASX), to exchange the full or partial structure of the administration shell.

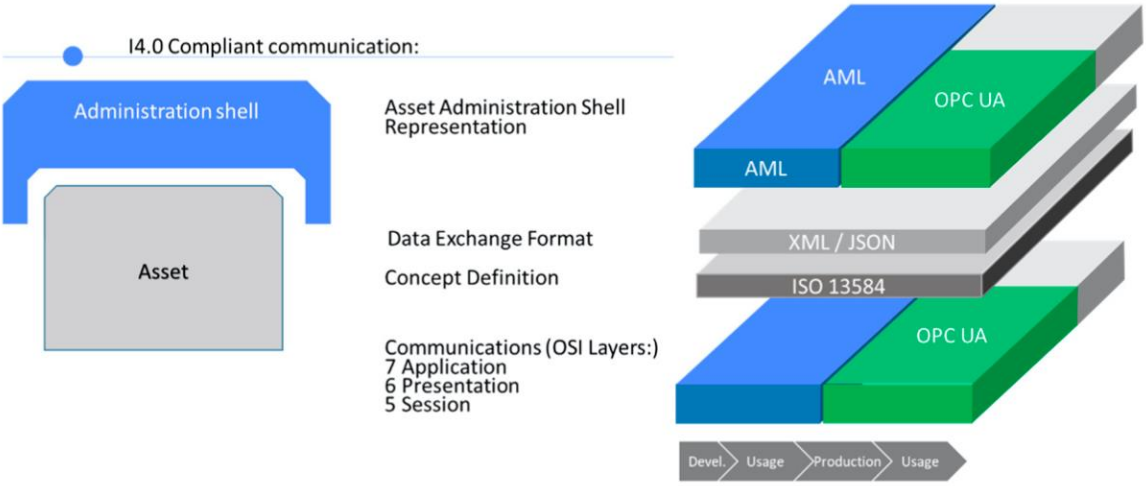

Figure 17. I4.0 Communication protocol stack

The AAS implements the Digital Twin concept meeting requirements of different use cases coming from several domains guaranteeing:

- **Interoperability**, companies can communicate and exchange information
- **Availability**, for every kind of product (non-intelligent and intelligent)
- **Integration** of value chains
- **Covering** of the complete life cycle of products, devices, facilities, etc.
- **Basis** for autonomous systems and AI

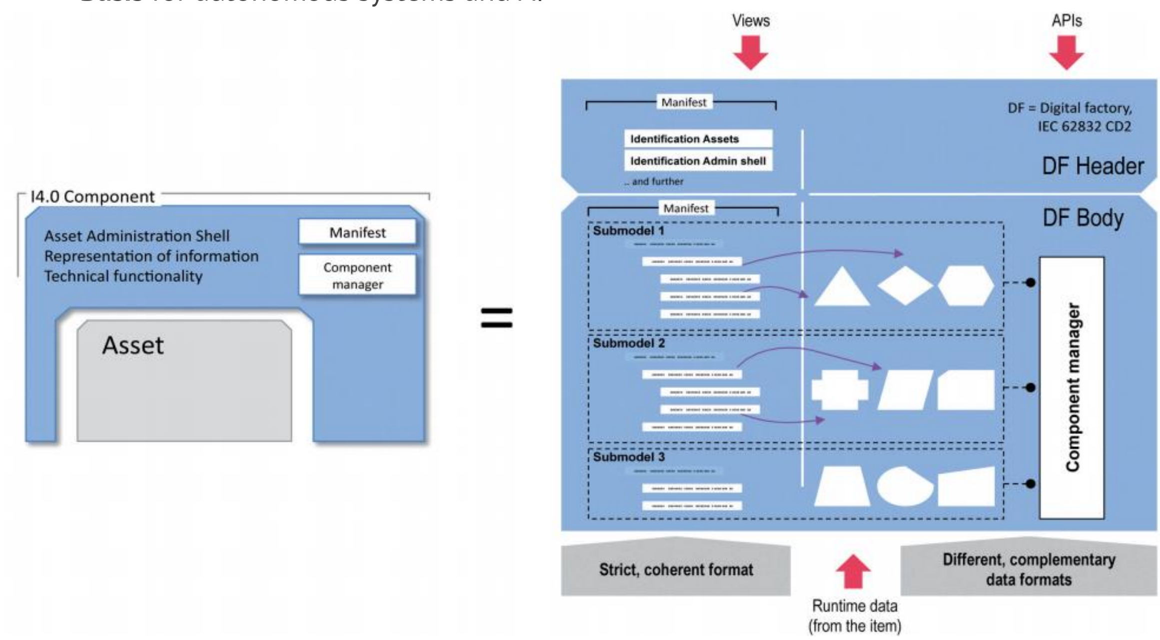

Figure 18. Asset Administrative Shell

The AAS can be provided in different implementation variants:

- **Passive** for example if the information is provided using a file or with IP/API-based access. In that case, the requested AAS is provided using a client/server pattern.
- **Active** corresponds to the peer-to-peer interaction pattern. The Administrative shells can communicate with each other using the Industry 4.0 language.

Starting from the above classification AAS implementation can be assigned in the RAMI4.0 Model covering different layers (Belyaev & Diedrich, 2019).

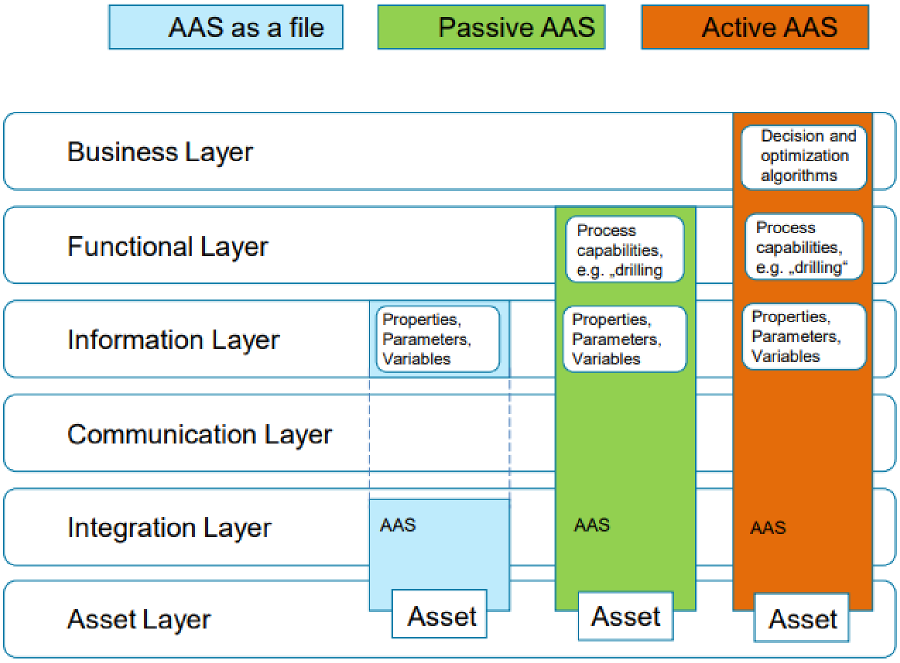

Figure 19. Assignment of the active AAS in the RAMI4.0-Model

3.3.3 Potential interest for i4Q

RAMI4.0 is able to describe and support different user perspectives, use cases and standards. RAMI4.0 offers more potential to various stakeholders in industrial production. The stakeholders' role and perspective will be explored in i4Q viewpoints.

The RAMI4.0 supports different standards in different layers. Regarding the communication layer, the OPC UA is the de facto standard, however companies can use unofficial or internal standards. This aspect referring to data models and communication will represent an interesting input for Task 2.2 and afterwards for the i4Q RA, especially in relation to the potential use of AAS.

3.4 Digital Factory Alliance

The Digital Factory Alliance (DFA)[20] is an initiative set-up by Innovalia, AtoS Research and Innovation and Engineering Ingegneria Informatica S.p.A in 2020. The Digital Factory Alliance (DFA) vision is that the successful implementation of outcome-based, resilient and sustainable production value chains depends on the capability of manufacturing factories to embrace true collaboration.

[20] https://digitalfactoryalliance.eu

3.4.1 Overview

The DFA envisions the development of an open and vibrant global business innovation community capable of shaping, steering and harmonising digital technology adoption (DFA manifesto) to support future strategic value chains. The DFA is born to put digital solutions (data-driven AI-powered) to work for advanced manufacturing processes. In the DFA, the manufacturing processes that interest industry the most are identified (green and zero-defect production, resilient logistics & supply chains, collaborative product & process engineering, predictive maintenance, etc…). No matter which digital manufacturing process the particular factory deploys today, the DFA Reference Architecture (RA) ensures that factories can continue evolving, enhancing and up- and down-scaling their engineering, manufacturing, and servicing strategies at the pace of their business and value chain development.

DFA represents the evolution of Digital Shopfloor Alliance (DSA) and refers to a Service Reference Framework (RF).

3.4.2 Main features

The DFA Industrial Big Data and Data Space RA need to be articulated and instantiated with the support of specific platforms, solutions, and infrastructures, so that the big data-powered AI-driven manufacturing processes can actually be realized. To facilitate replicability and transferability of digital factory solutions, the DFA provides the Digital Service RA (DS-RA), which ensures a broad industrial applicability of digital enablers, mapping the digital technologies to different areas and to guide technology interoperability, federation, and standard adoption. The DFA DS-RA design complies with ISO/IEC/IEEE 42010 architectural design principles and provides an integrated yet manageable view of digital factory services. In fact, DFA DS-RA integrates functional, information, networking, and system deployment views under one unified framework. The DFA DS-RA address the need for an integrated approach to how (autonomous) services can be engineered, deployed, and operated/optimized in the context of the digital factory. The DFA DS-RA is composed of three main pillars:

1. Digital Service Engineering.
2. Digital Manufacturing Platforms & Service Operations.
3. Sovereign Digital Service Infrastructures.

The DFA RA is aligned with ISO 20547:2020 "Big Data Reference Architecture" and DIN SPEC 27070:2020 "Security Information Gateway RA". Moreover, the DFA RA integrates the 6 layers of the RAMI 4.0 IEC 62264:2013 and IEC 61512:1997 Hierarchy Layers (product, field and control devices, station, work-centre, enterprise and connected world). The RA is composed of four layers that address the implementation of the 6 big data "C" (Connection, Cloud/edge, Cyber, Context, Community, Customisation) required for implementation of data-powered AI-driven digital manufacturing processes. These 4 layers map to the four intelligence levels considered by the Zero Factory, i.e., smart asset functioning, reactive reasoning, deliberative reasoning and collaborative decision support.

The digital service pillar is decomposed in various layers as follows:

- **Enterprise.** The enterprise layer is the top layer of the reference service framework and encompasses all IT enterprise services.
- **Factory.** At the factory layer, a single factory is depicted. This includes all the various workcells or production lines available for the complete production. This layer is connected to services needed to manage the production holistically.
- **Workcell/Production Line.** The workcell layer represents the individual production line or cell within a company. Nowadays, a factory typically contains multiple production lines (or production cells), where individual machines, robots, etc. are located. Therefore, this layer refers to services mainly addressed to the management and operation of such working environments.
- **Field Devices.** The field devices layer is the lowest level of the reference architecture, where the actual machines, robots, conveyer belts, etc., but also controllers, sensors and actuators are positioned. This layer is also the one where the actual product is placed. Therefore, embedded services related to the control and operation of the individual machines and manufactured products are placed in this layer.

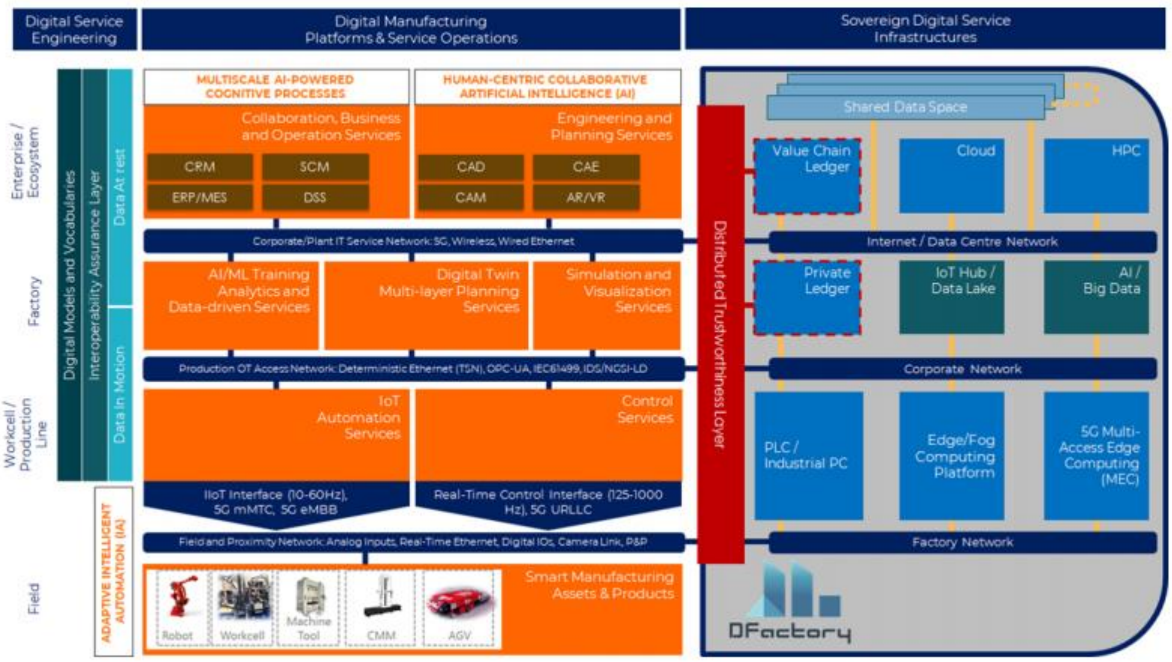

Figure 20. Digital Service Reference Architecture

3.4.3 Potential interest for i4Q

The DFA RA is independent of the specific digital manufacturing process and the specific factory deploys. The interesting aspect to be considered in the i4Q RA is the data-driven AI powered layer to work for advanced manufacturing processes. In particular, the Digital Service Engineering vertical pillar defines a data classification aligned with the most common I4MS (ICT Innovation for Manufacturing SMEs) architectures, interoperability service meets i4Q requirements as well as the data representation (Digital Models and Vocabularies).

3.5 BDVA Reference Architecture

The BDVA Reference Architecture is a reference framework made by the European BDVA (Big Data Value Association) that describes logical components of a generic big data system (BDVA, 2017).

3.5.1 Overview

The Strategic Research and Innovation Agenda (SRIA) defines the overall goals, main technical and non-technical priorities, and a research and innovation roadmap for the European Public Private Partnership (PPP) on Big Data Value.

BDVA has proposed their initiative regarding a European Data-Driven Artificial Intelligence and their vision regarding AI and Big Data and how it can drive the European technology and economy (BDVA, 2018). To realize this vision, it will be necessary to address a number of challenges:

a) Data-driven AI-based solutions for the industry will require new business models.
b) Trust in AI and its results must be established; for example, one should be able to explain how AI applications came to a specific result ("Explainable AI"), which would foster responsible technological development (e.g., avoid bias) and enhance transparency in how and why an AI takes a decision.
c) It is necessary to develop an AI and Big Data ecosystem, by developing data for open AI platforms and overcoming the lack of data interoperability.
d) Fuse and develop a number of technologies, as a successful industrial AI relies on the combination of a wide range of technologies, such as advanced data analytics, distributed AI, and hardware optimized for AI.

3.5.2 Main features

In the context of this deliverable the most important information is related to the Reference Model, for the overall positioning of concepts and the technical priorities, for the relation with manufacturing scenarios. The BDVA Big Data Value Reference Model can be seen in the following figure.

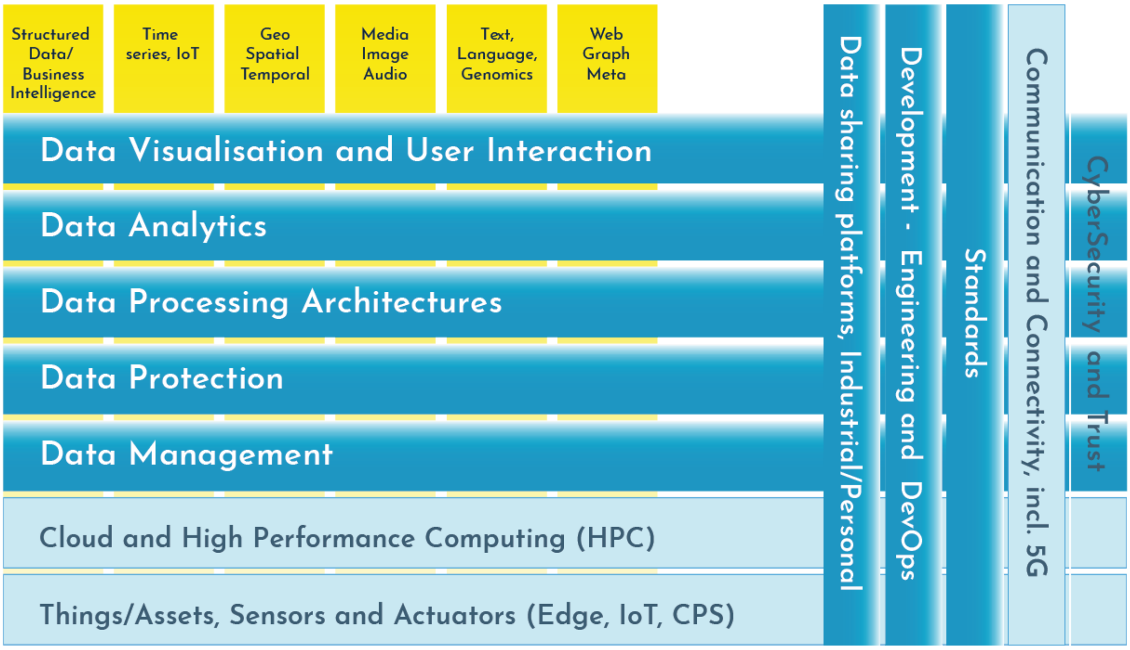

Figure 21. The BDV Reference Model

The BDV Reference Model is structured into horizontal and vertical concerns:

- Horizontal concerns cover specific aspects along the data processing chain, starting with data collection and ingestion, and extending to data visualization. It should be noted that the horizontal concerns do not imply a layered architecture. As an example, data visualization may be applied directly to collected data (the data management aspect) without the need for data processing and analytics.
- Vertical concerns address cross-cutting issues, which may affect all the horizontal concerns. In addition, vertical concerns may also involve non-technical aspects.

Technical priorities that are relevant as expressed in the BDV Reference Model are the following:

1. **Data Visualization and User Interaction**: Advanced visualization approaches for improved user experience. This technical priority is addressing the need or advanced means for visualization and user interaction capable to handle the continuously increasing complexity and size of data to support the user in exploring and understanding effectively Big Data.
2. **Data Analytics**: Data analytics to improve data understanding, deep learning, and meaningfulness of data. The Data Analytics technical priority aims to progress data analytics technologies for Big Data in order to develop capabilities to turn Big Data into value, but also to make those approaches accessible to the wider public.
3. **Data Processing Architectures**: Optimized and scalable architectures for analytics of both data-at-rest and data-in-motion with low latency delivering real-time analytics. This technical priority is motivated by fast development and adoption of Internet of Things (IoT) technologies that is one of the key drivers of the Big Data phenomenon with the need for processing immense amounts of sensor data streams.

4. **Data Protection**: Privacy and anonymization mechanisms to facilitate data protection. This is related to data management and processing, but it can also be associated with the area of Cybersecurity.
5. **Data Management:** Principles and techniques for data management. This technical priority is motivated by the data explosion that is mainly triggered by the increasing amount of data sources (e.g., sensors and social data) and their complexity in structure.

To this end, recently Big Data Value Association (BDVA) and euRobotics have launched the creation of the Data, AI and Robotics Association (DAIRO) PPP (public-private partnership) (BDVA & euRobotics, 2019). The wider purpose of objectives and activities are Big Data Value, AI, Data and Robotics.

This new association objectives are to boost European AI (Artificial Intelligence), Data and Robotics research, development and innovation, and to foster value creation for business, citizens and the environment.

Moreover, the aim of this association is:

- boosting European competitiveness, societal wellbeing and environmental aspects
- promoting the widest and best uptake of AI, Data and Robotics technologies and services for public, professional, and personal use;
- establishing the excellence in science and business in AI, Data and Robotics.

3.5.3 Potential interest for i4Q

The BDVA reference model provides a clear and comprehensive overview of concerns at the intersection of Big Data and cloud platforms. BDVA analyses current gaps and challenges for dynamic data and formulates a list of necessary advancements.

BDV Reference Model pursues a data-driven oriented approach; even if i4Q will not follow such a kind of model, BDV layers could represent an interesting aspect for some of i4Q possible components and sub-components, with reference to the i4Q Solutions functionalities.

Moreover, the approach used by BDV to characterize the data across layers, could represent an interesting idea for the i4Q RA for a granular data view with a high level of detail.

4. i4Q Architectural Framework

Following the principles and guidelines defined in the methodology presented in Section 1, a first release of the i4Q Architectural Framework has been elaborated and described in the following.

The adopted approach provides a holistic view on the i4Q Solutions, identified as the main building blocks for the architectural design. The project solutions represent, in fact, the main sub-systems identification that will be integrated with the requirement analysis and functional specifications (T1.4) in the next Reference Architecture release (D2.7 - i4Q Reference Architecture and Viewpoints Analysis v2).

4.1 i4Q Reference Architecture

The i4Q Reference Architecture (i4Q RA) defines a conceptual framework aiming to be the canvas for the design, implementation and integration of the i4Q Solutions. The i4Q RA is aligned to the most common standard reference architectures in the manufacturing domain described in Section 3. In particular, two approaches have been adopted:

- The IIRA three-layers architectural pattern as the main design driver.
- The IIRA layered databus pattern in order to make the solution data-driven.

The mapping between the layered databus pattern with the three-tier architecture pattern is as follows:

- The Machine Databus is mapped with the physical Assets and Smart Products.
- The Unit Databus is mapped with the Edge Tier.
- The Site Databus is mapped with the Platform and Enterprise Tiers.
- The Inter-Site Databus enables ecosystems and inter-factory communications.

The i4Q RA Security and Compliance Layer supports the communication between all tiers, providing a common security layer for accessing and retrieving data and physical assets (sensing and actuation).

Furthermore, the i4Q RA is able to support data (and services) description through the most significant meta-models (i.e., IIRA Characteristics of IIoT Information Models[21]), common ontologies and digital models analyzed in T2.2 and described in D2.2. Finally, the Interoperability Assurance Layer guarantees interoperability inside the i4Q ecosystem considering the broad-spectrum of raw and elaborated data that can be processed by the different solutions.

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[21] https://www.iiconsortium.org/pdf/Characteristics-of-IIoT-Information-Models.pdf

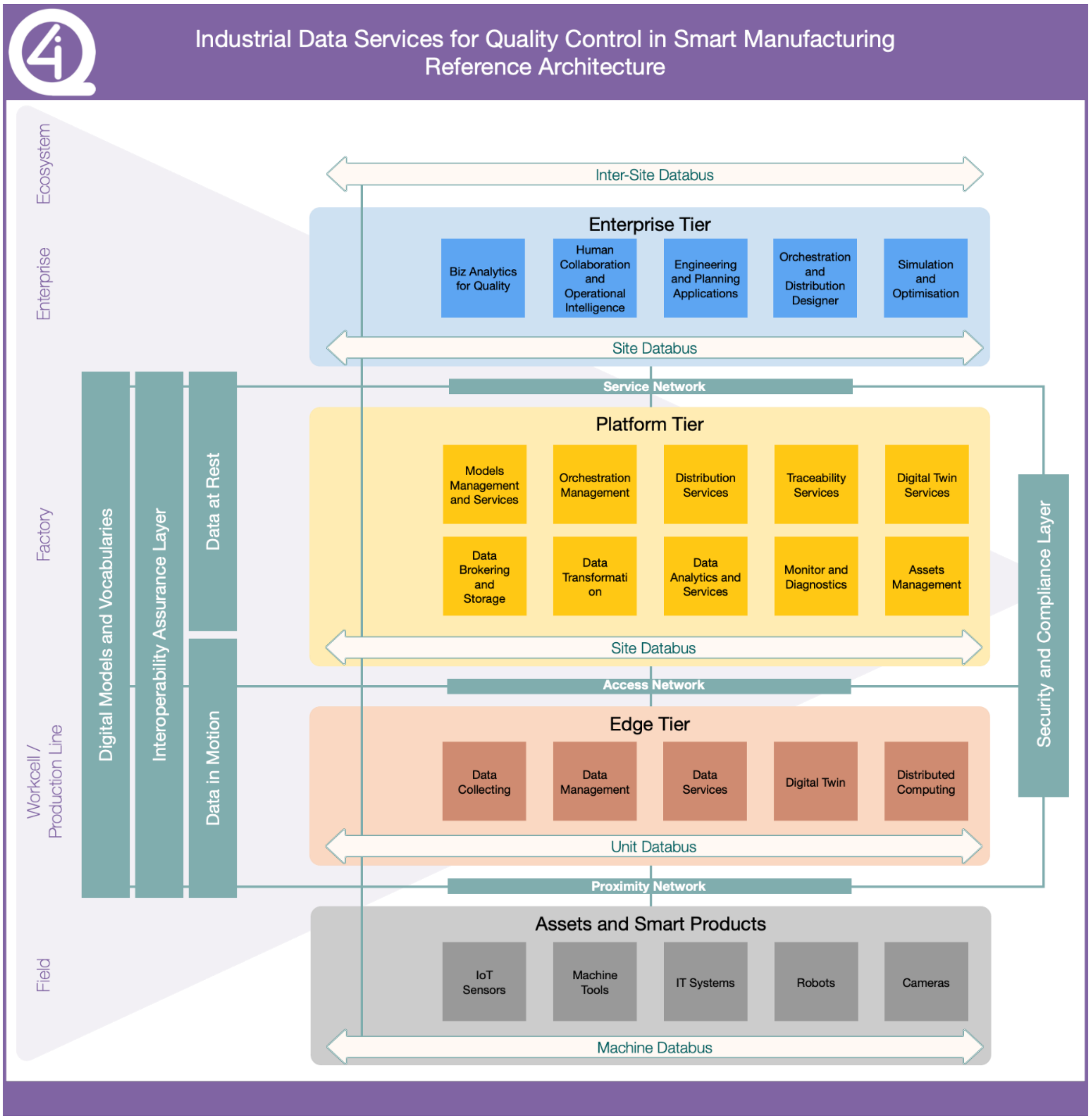

Figure 22. i4Q Refernce Architecture

4.1.1 Edge Tier

The Edge Tier aims to implement the sensor and control domain. It allows to connect the physical assets and systems, collecting and processing data in the "proximity network". Furthermore, it supports the Digital Twin (enabling advanced use, i.e., data filtering for generating a more precise virtual object, real-time analytics, etc.) and the Distributed Computing for sustaining distributed workloads and models. The Edge Tier, typically, process real-time data (Data in Motion).

The Edge Tier includes applications and services for describing and managing data, supports the digital twins reducing the connectivity and latency issue, and the distributed computing devising a typical edge-cloud orchestration system.

4.1.2 Platform Tier

The Platform Tier contains applications and services for supporting the data flow (abstracted data) acting as a middleware between the Edge Tier and the Enterprise Tier (and between access and service network). It supports services for quality control (modelling, orchestration, traceability, etc.) and historical data processing (Data at Rest).

The Platform Tier includes subcomponents for integrating third-party systems and architectures, the Digital Twin services for interacting with the edge-related application, and the distribution services (i.e., resource management, data, and algorithms orchestration, etc.).

4.1.3 Enterprise Tier

The Enterprise Tier implements business specific applications related to quality control, providing interfaces for end-users. It integrates engineering and management applications for supporting command generations, operational intelligence operations, big data analytics and service orchestration.

The Enterprise Tier includes an "open" (not exhaustive) catalogue of use case/domain-specific applications. The usage of standard APIs and commons ontologies drives the definition of the common interfaces and facilitates the integration of (user and system) legacy and newer applications.

4.2 Mapping i4Q Solutions against i4Q RA: preliminary evaluation

This first version of the i4Q Reference Architecture has been designed basing on the project view and main principles. The architecture will be refined in the second final version at M9, receiving inputs from requirements elicitation and viewpoints definition. This architecture will guide future developments for the "building activities" in WP3, WP4 and WP5, where the 17 tools (part of the 22 i4Q Solutions) will be implemented. So, it is very important to have a strong connection between the RA and the 22 i4Q Solutions. In order to have a coherent inclusive vision provided by the i4Q RA, we have started mapping a very limited subset of solutions in the RA. This activity will be finalized during next months and will provide interesting inputs for the final i4Q RA.

At the moment, five solutions have been evaluated: we have assessed which architectural components each solution will be based on, verifying the large comprehensive scope of the of architecture in pursuing project objectives.

In the following pictures, the mapping with the i4Q RA elements has been highlighted; two different colours have been used: one to identify the sub-component the solution is mapped to (red), and another one to show other outstanding related sub-components (orange).

According to the iterative process approach, these mapping will be improved during next months and will help to position all the i4Q Solutions with respect to the RA in a consistent way.

4.2.1 i4Q^BDA Big Data Analytics Suite

The Big Data Analytics Suite main function is to deliver on-demand deployment bundles that are easily configurable, deployable and executed. The objective is to manage raw data, and from it, generate information to improve the supervision of all supply chain and production stages, from the shop floor to the office floor. We have a set of technologies grouped together efficiently gather, harmonize, store and apply analytic technics to data generated by sensors and other Cyber Physical Systems mounted on facilities. This Suite will be able to provide custom-built deployment bundles that can contain all the necessary tools, methods, libraries and code to deploy and run the selected Data Analytics tasks in a panoply of environments, from centralised, distributed on-premises or Cloud. This solution will be supported by containerization technologies such as Kubernetes or Docker.

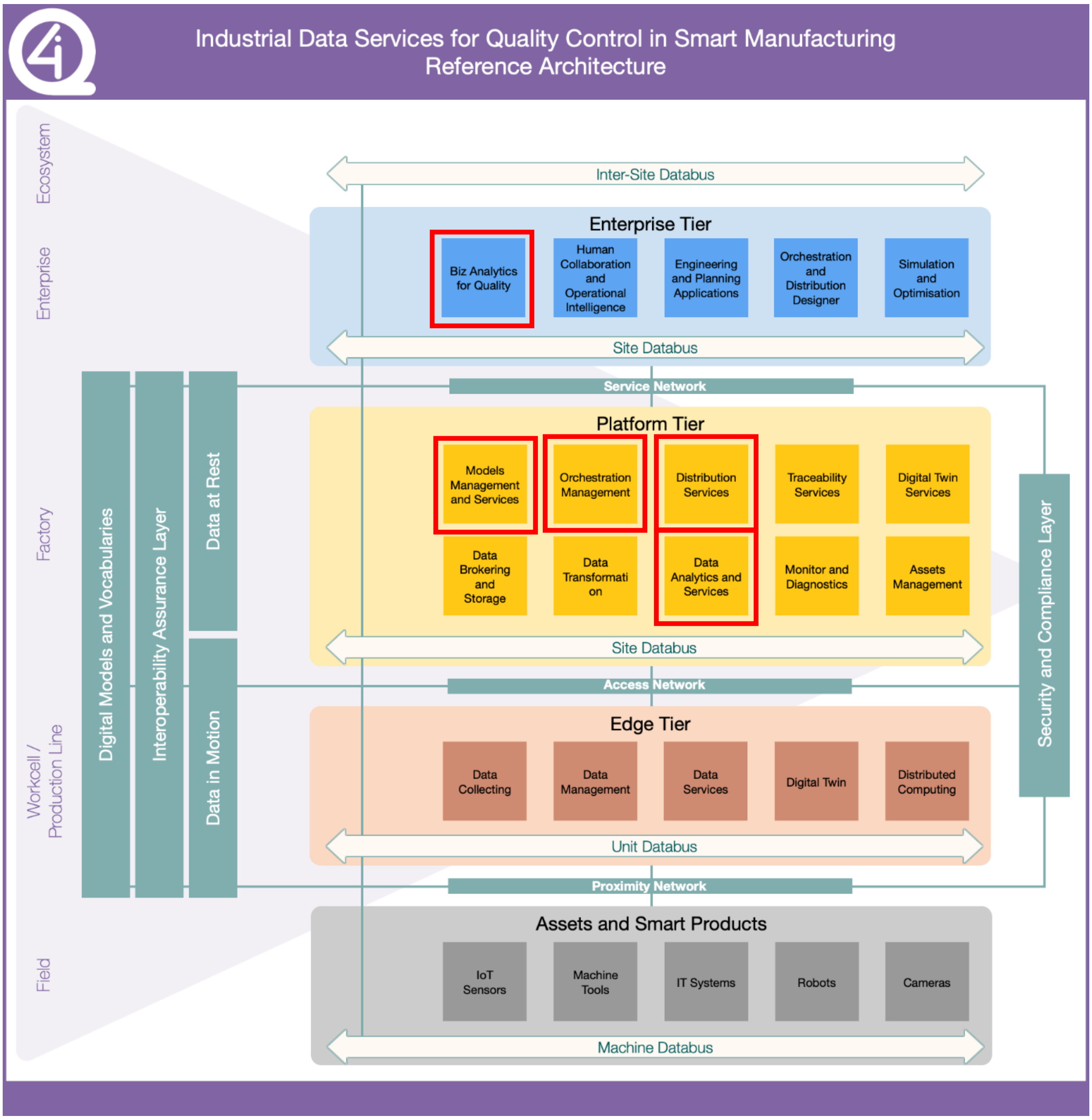

Figure 23. i4Q RA mapping with i4Q^BDA Big Data Analytics Suite

The i4Q^BDA solution is mapped to sub-components in the Platform and Enterprise Tiers of the i4Q RA. On the Platform Tier, this solution is responsible for the provision of Big Data Analytics tools and methods, through ready-to-deploy software bundles, enabling true Software-as-a-Service. Hence, the Data Analytics and Services and Model Management and Services sub-components will be the basis for the tools and methods provided by the i4Q^BDA, while the Distribution Services sub-component will support the configuration of the software bundles for the envisaged deployment scenarios. Further, the provided bundles will have access to configuration and orchestration tools to optimize their deployment. Hence, these two sub-components are of vital importance for this solution. Finally, in the Enterprise Tier, the i4Q^{BDA} solutions, as its counterpart, the i4Q^{DA}, will be responsible for enabling Big Data & Business Analytics Services for Quality Assurance.

4.2.2 i4Q^{DA} Services for Data Analytics

The main functions of this solution are the provision of Data Analytics services, supported by the integration of several state-of-the-art tools, methods and libraries, ranging from Big Data Processing and Analytics to Machine Learning, Data Mining and Deep Learning. The services will be provisioned through two main channels: i) Open APIs (RESTful-based, pub-sub, socket-based) for the collection of the necessary data to execute the selected services and for the provision of results coming from the Data Analytics services, or ii) Deployment bundles with the necessary tools, methods and libraries to deploy and run the selected services on premises or on cloud environments.

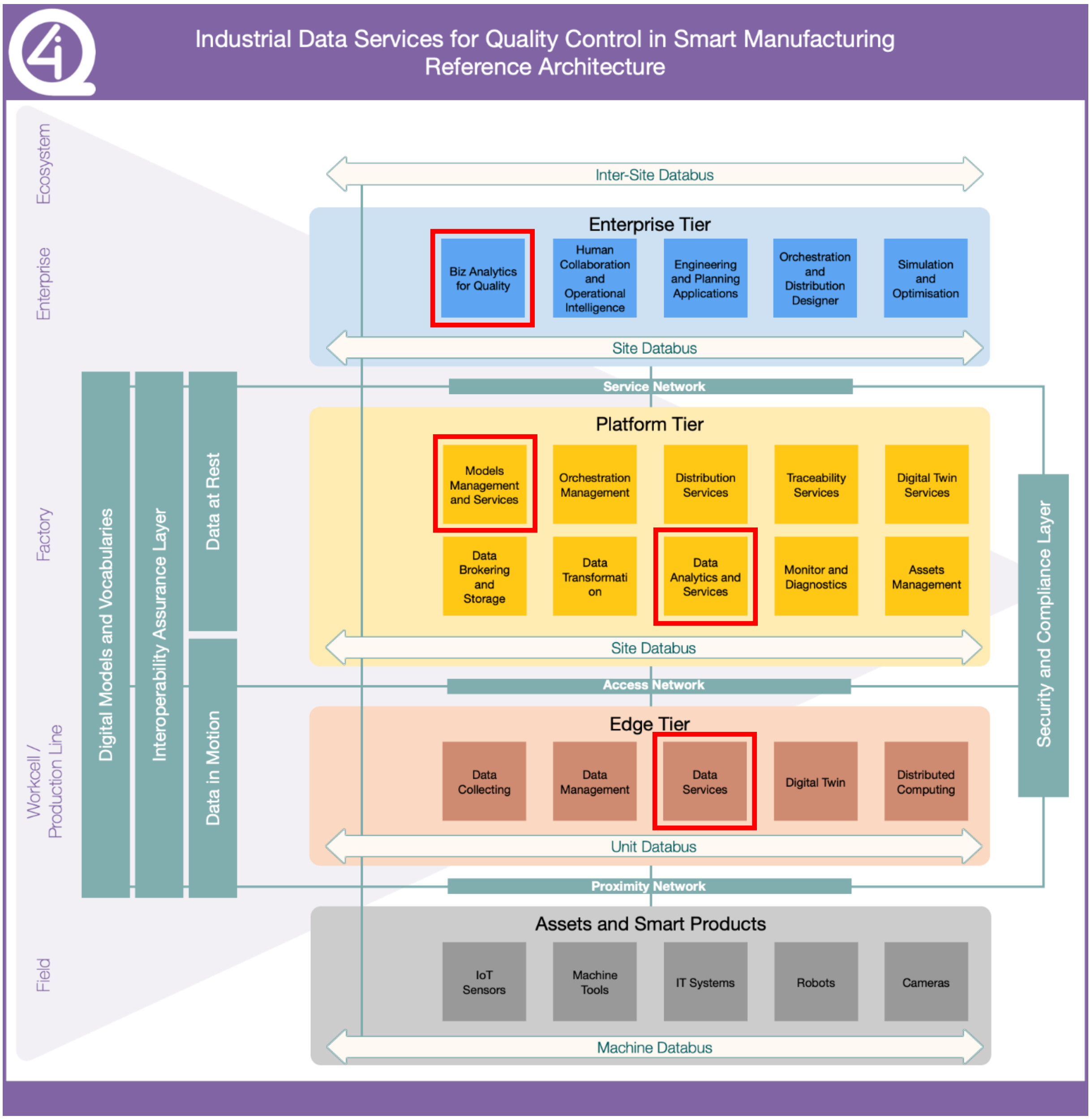

Figure 24. i4Q RA mapping with i4Q^BA Data Analytics Services

The i4Q^DA solution is mapped to the Edge, Platform and Enterprise Tiers of the i4Q RA. In the Edge Tier, the edge data analytics services will be provided by i4Q^DA, while on the Platform Tier, this solution is responsible for the provision of Data Analytics and Models Services. Finally, as in the case of its counterpart, the i4Q^DA solution, this solution will also be responsible for the Business Analytics for Quality Assurance sub-component in the Enterprise Tier.

4.2.3 i4Q^AD Analytics Dashboard

This solution has the main function of providing visual analytics tools and methods to the i4Q project. The i4Q Analytics Dashboard can be used via a Web Application or through the provision of a deployment bundle that can be deployed on premises or on the cloud, and will be based on state-of-the-art visual analytics tools, such as Apache Superset, Grafana or Jupyter Notebooks.

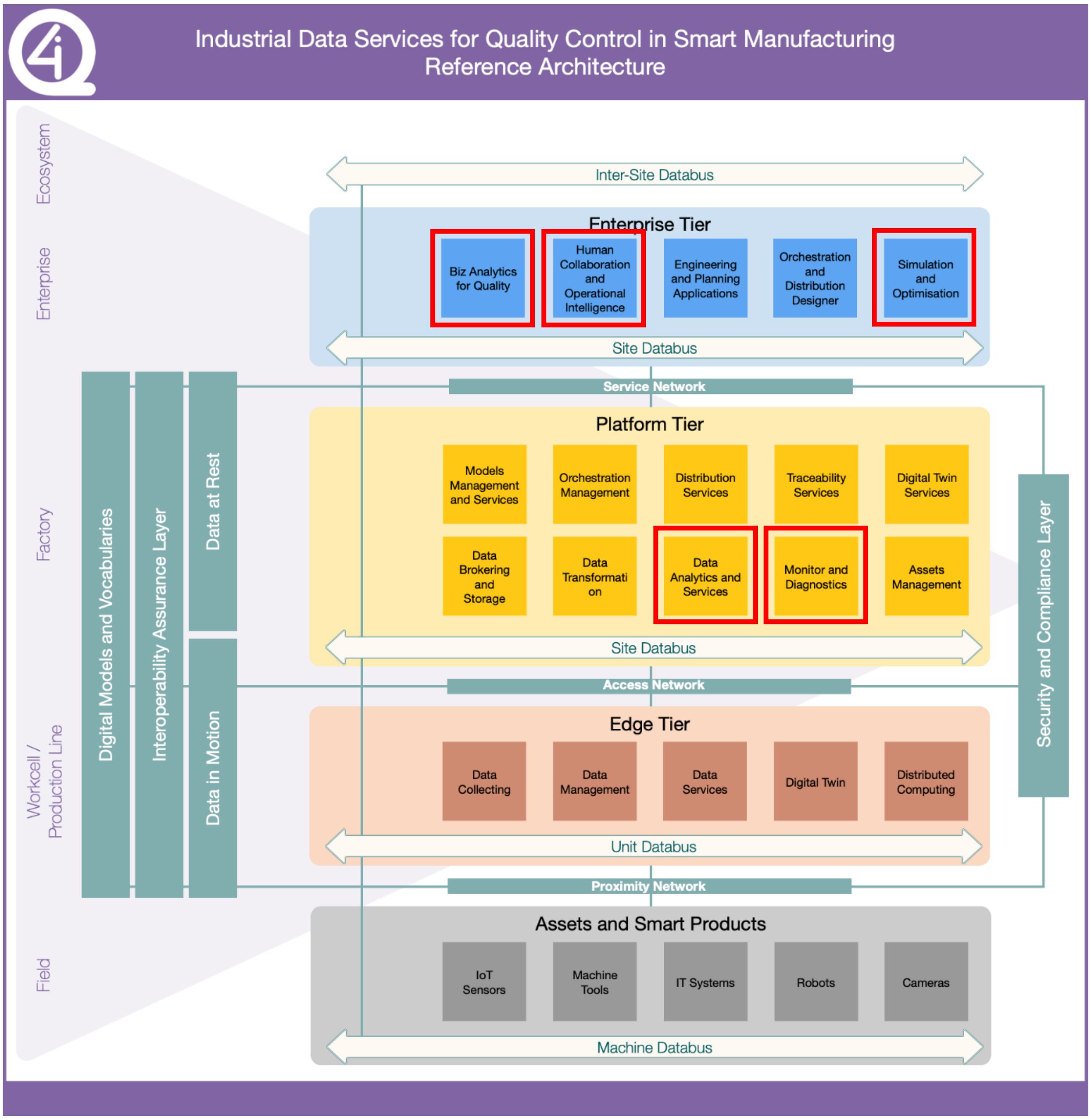

Figure 25. i4Q RA mapping with i4Q^AD Analytics Dashboards

Regarding the mapping of the i4Q^AD solution to the i4Q RA, it is mainly based on the Platform and Enterprise Tiers. In the Platform Tier, the i4Q^AD is responsible for delivering reporting, dashboarding and visual analytics capabilities to the platform, which can be mapped to the Data Analytics and Services and the Monitoring and Diagnosis sub-components. On the Enterprise Tier, the i4Q^AD solution will support the Business Analytics for Quality, Human Collaboration & Operational Intelligence and the Simulation & Optimization sub-components, by providing the necessary visual analytics tools and methods, reports and dashboards.

4.2.4 i4Q^QD Rapid Quality Diagnosis

i4Q^QD solution is a micro-service that provides smart alerting and quality diagnosis. It aims to evaluate the process' quality during manufacturing. It is a micro-service for providing rapid diagnosis of manufacturing line on the possible cause of failures, evaluating data fidelity, product-quality and process condition, and providing action recommendations for sensor/data processing recalibrations, process line/machine reconfiguration or maintenance actions.

i4Q^{QD} can be used by the machine/system operator, manager owner or the manufacturer and it is a software solution, which handles real-time data and allows operations during the manufacturing process. It detects failures in the quality of the products during manufacturing and send notifications/alerts to the system operator. It also includes 2D and 3D feature toolkits in order to be user-friendly to the end-users and to allow fast and efficient handling.

To ensure the function of the manufacturing line, the following aspects should be monitored by i4Q^{QD}:

- Evaluation of data
- Product quality
- Process condition
- Maintenance actions
- Machine reconfiguration

i4Q^{QD} can be utilised in combination with other i4Q Solutions, such as i4Q^{IM} and the main input data is real-time sensor's data (both in the Edge and the Platform tier of the i4Q reference architecture). The output of the solution is the data visualization in different forms (2D, 3D visualization, virtual sensors’ graphs, timeseries graphs) (Enterprise tier of the i4Q reference architecture).

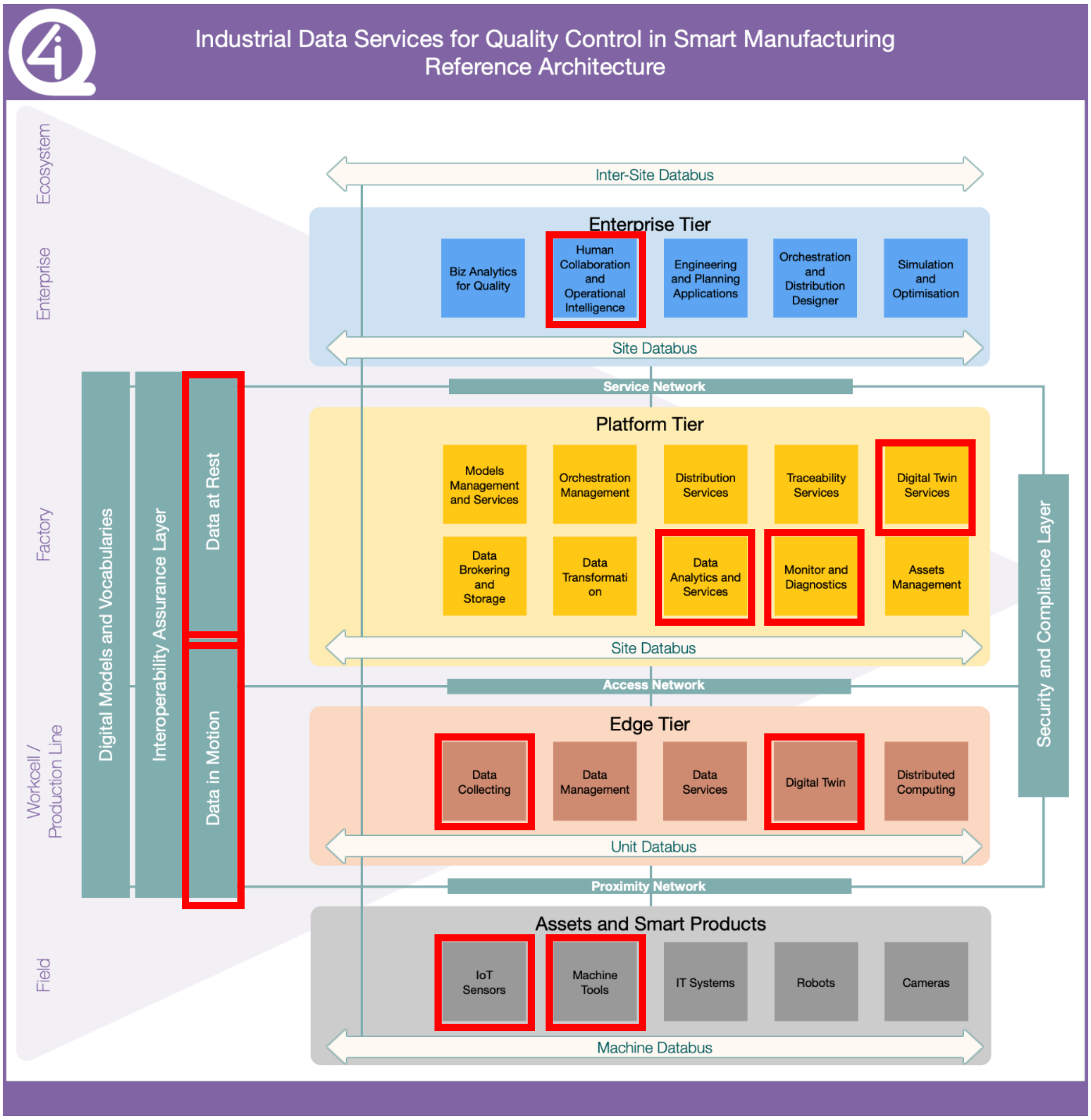

Figure 26. i4Q RA mapping with i4Q^D Rapid Quality Diagnosis

4.2.5 i4Q^LRT Manufacturing Line Reconfiguration Toolkit

The objective of this toolkit is to increase productivity and reduce the efforts for manufacturing line reconfiguration through AI. This tool consists of a set of analytical components (e.g., optimisation algorithms, machine learning models) to solve known optimisation problems in the manufacturing process quality domain, finding the optimal configuration for the modules and parameters of the manufacturing line. Fine tune the configuration parameters of machines along the line to improve quality standards or improve the manufacturing line set-up time are some examples of the problems that the i4Q^LRT solves for manufacturing companies.

The Manufacturing Line Reconfiguration Toolkit is mapped to the Simulation and Optimisation sub-component of the Enterprise tier. To facilitate the interconnection between processes and to scale the deployment of solutions across different industries and sectors, it is important that the algorithms are semantically interoperable and that all use the i4Q digital models and ontologies. Also, to ease integration and interoperability with other i4Q solutions, they all must use the same services to access data at rest and data in motion for model instantiation and execution. To address this, the strategy is to wrap algorithms into an interoperability layer that will implement the different cross-cutting functions (clients to data services, security and compliance services, libraries for digital models and vocabularies). The interoperability layer will also provide endpoints so that other solutions can instantiate and run the algorithms in complex workflows.

Some of these workflows may require that models are executed at the edge tier, close to the data source, to minimise latency. Therefore, the interoperability layer must ensure that the algorithms are deployable at the edge, through the Distributed Computing sub-component, and manageable by the Orchestration Management Sub-component.

Finally, to enable the digital twinning of models and algorithms with the underlying physical architecture, they should be regarded as (virtual) assets. For instance, an algorithm to optimise (i.e., fine tune) the configuration parameters of a machine should be regarded as a feature of its digital twin, and in that sense, the services provided by the interoperability layer should be mappable as features of the digital twin.

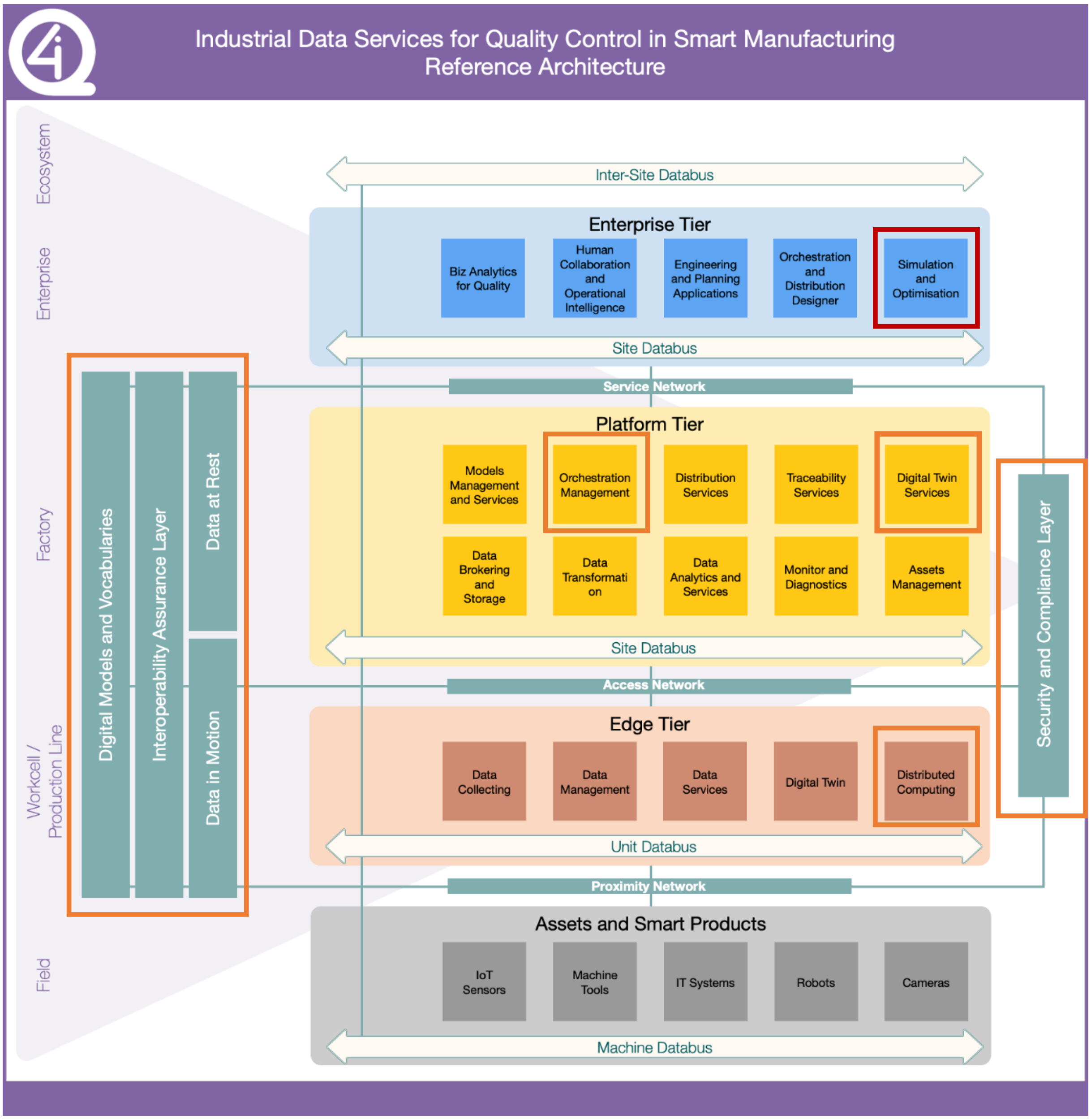

Figure 27. i4Q RA mapping with i4Q^LRT Manufacturing Line Reconfiguration Toolkit

4.3 Alignment with i4Q requirements

In this section we briefly describe the way the project's needs will be aligned with the requirements. The list of the requirements is currently ongoing and not finalized yet.

In order for the requirements of the project to be met, preliminary actions must be taken. First of all, the requirements of any kind must be identified and explicitly described by the respective partners. All partners involved should decide on a methodology to define, group and analyse them. The requirements are usually analysed across the functionalities of a project, so they can cover the project's needs. Dividing the requirements in categories (functional/ non-functional, user-solution provider-technical-system-software) will assist in the implementation of the project's solutions and will assist the developers. The final list of the requirements should be agreed upon all partners, however a strategy should also be planned to manage any changes that may come up in the requirements' list, since some of them could be dynamic. The partners will also ensure the mapping of different categories of requirements, e.g., the software requirements should cover the user requirements, or the architectural structure should be built upon the system requirements. Developers need to follow the users/pilots' requirements when building the solutions.

5. i4Q RA: main viewpoints

The i4Q RA will incorporate all the relevant perspectives (which in i4Q we call 'viewpoints') involved in the smart manufacturing process and in particular related to addressing the data reliability challenges in turn related to the smart manufacturing, high quality production process. i4Q RA will be structured around four viewpoints in order to offer a framework to think iteratively through the architectural issues that may arise during its conception. This section sets up the main viewpoints which will drive the design and implementation of the i4Q RF: Business, Usage, Functional and Implementation Viewpoints.

5.1 Business viewpoint

In the RA definition, one the main objective is to avoid the risk of a "technology-centric"' approach; for this reason, the viewpoint definition will start with the analysis of a business point of view. This will allow us to incorporate already in the (early) design requirements and needs which are closer to real world, operation needs. To this end the business viewpoint definition will focus on framing the vision, values and key objectives.

The i4Q Reference Architecture will be characterized from the business, regulatory and stakeholders' point of view. First of all, an analysis of stakeholders will be performed, taking into account the input resulting from WP7 (Communication, Dissemination and Standardisation) discussions.

Two main types of stakeholders will be identified:

- Business Decision-Makers,
- Product Managers and System Engineers.

Business-oriented concerns such as business value, expected return on investment, cost of maintenance and product quality will be evaluated when considering the i4Q RIDS as a solution to business problems.

Stakeholders have a major stake in the business and strong influence in its direction. It is important to identify major i4Q stakeholders and engage them early in the process of evaluating these business-oriented concerns. In conceptualizing and defining the i4Q Solutions, technological and business factors will have to be considered, including external influences from technological trends, specific market condition and potential, customer inputs, and regulatory requirements (in the areas of, e.g., safety, privacy, environmental and labour).

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

- **Vision**, describing a future state of an organization or an industry, including the business direction toward which an organization executes and providing values reflecting how the vision may be perceived.
- **Values**, reflecting how the vision may be perceived by the stakeholders who will be involved in funding the implementation of the i4Q Solutions as well as by the users of the resulting project tools.

- **Key objectives**, quantifiable high-level technical and ultimately business outcomes expected of the i4Q Solutions in the context of delivering the values. Key objectives should be measurable and time-bound.
- **Fundamental capabilities**, referring to high-level specifications of the essential ability of the i4Q Solutions to complete specific major business tasks. Key objectives are the basis for identifying the fundamental capabilities. Capabilities should be specified independently of how they are to be implemented (neutral to both the architecture and technology choices) so that system designers and implementers are not unduly constrained at this stage.

For the i4Q objectives it is very important that both types of stakeholders (business and technical) will take part in different phases to identify these fundamental elements.

In addition to stakeholders' definition (in terms of values, objectives, etc.), in the i4Q analysis a step-by-step approach will be adopted to define:

- Stakeholders' relations
- Business model(s) (how do these affect the architecture)
- Licenses and patents (how do these affect the architecture)
- Accountability (e.g., in relation to anything involving AI)
- Risks and liabilities

5.2 Usage Viewpoint

The usage viewpoint will use the objectives gathered in the business viewpoint in order to identify the means in which the system will be used, including the parties and activities participating in it.

These activities will serve as an input for the system requirements, and will guide its design, implementation, deployment, operations and evolution, that will be later used in the functional viewpoint. In this section, we will take a first approach in the matter, trying to find out roughly some of its agents (those being the parties, roles, activities and tasks). More details about the usage viewpoint will be available in the future deliverables corresponding to Task 2.4.

In the first place, we need to focus on the i4Q scope. The main objective of i4Q is to provide data services for quality control in the industries 4.0 paradigm. Taking this into account, we can state that using i4Q means using any of the provided data services. Although we are in an early stage and they are yet to be defined, we know that these services will cover a wide scope of functionalities. The i4Q services will follow the smart manufacturing premises, meaning that sensors, automation, data collection and its analysis will take a big role in the conception of these services.

Then, we can study which parties will interact with the system, their characteristics and the training they require. These parties are defined in the IIRA document as agents, human or automated, that have autonomy, interest and responsibility in the execution of tasks. Following this definition, we can state that all the personnel, machinery and sensors that take part both in the manufacturing and quality testing processes will be active parties of the system. Starting with the personnel we can identify some profiles:

- **Factory operator**. It will be the person operating some machinery in the manufacturing process. This profile will require extra training, as it will have to incorporate any given feedback from the quality assurance process or any of the data services that may affect its workflow.
- **Data analyst**. It will be the person studying and analysing the data collected by the sensors. Applying some Machine Learning techniques over this data, they might be able to optimize any of the industrial processes. They require no extra training, as they should be experts on the matter.
- **System administrator**. It will be the person in charge of maintaining and managing the system.

As for automated agents, we can identify:

- **Machinery**: Any piece of equipment that takes part in the manufacturing process. It might have to be adapted to accept new incoming inputs from the system in order to tune its behavior, as it will improve its performance.
- **Sensors**: Any device that can take measurements in the manufacturing or quality testing processes. The data collected by them will be processed and studied by the data analyst in order to enhance those industrial processes.

Finally, as the transition to this new industrial scheme can be a complex process, some manuals and documentation will be provided to each stakeholder. These documents will help them to better understand how the system works and how to make the best use possible out of it.

5.3 Functional Viewpoint

The functional viewpoint focuses on the functional components in i4Q Solutions. It considers their structure, interfaces and interrelation, the relationship and interaction of the solutions between them, supporting their uses and activities. These elements are coordinated by activities (usage viewpoint) and supportive of the system capabilities (business viewpoint).

i4Q Solutions provide a complete solution consisting of a collection of different services for the treatment of sustainable and reliable industrial data based on the IoT. Thanks to these services, it will be possible to manage the large amounts of industrial data coming from all the IoT devices within the factory that are interconnected for monitoring on the manufacturing line. All of it is modularized and includes a microservices-oriented architecture for the end user.

Based on the Industrial Internet Reference Architecture (IIRA) document, it defines within the functional viewpoint a series of decomposition of the functional domains to try to generate a functional architecture within these domains. These domains are defined in the IIRA document in five functional domains (Control, Operations, Information, Intelligence, Application and Business). For i4Q Solutions, we adapt this domain model and define them as follows:

- **Control Domain**: It is a set of functions that are performed in industrial control systems. The solutions that apply these functions are implemented close to the physical systems that control them, so they may be geographically distributed and difficult to access.

- **Operations Domain**: These are solutions whose function consists of provisioning, managing, monitoring, and optimizing solutions in the control domain.
- **Information Domain**: These are solutions which function is to collect data from several domains, especially the control domain, and analyse this data to acquire high-level intelligence about the overall system. To obtain the data, it uses the control domain solutions, which make it possible to control the physical systems.
- **Application Domain**: A set of functions that implement logic, rules, and application models at a high and detailed level for application optimization.
- **Business Domain:** this is a set of functions focused on end-to-end operations using the different i4Q Solutions. An example would be enterprise resource planning (ERP) with factory execution systems (MES).

5.4 Implementation Viewpoint

This is the last i4Q RF viewpoint in which will be described technically and in detail, all the system components of the framework and how they are interconnected, over the base of already selected technologies that are required for its implementation. All the details of implementation viewpoint will be described in Task 2.6.

The previous viewpoint is the functional viewpoint that provides the functional components within the i4Q system, that is:

- technologies needed to implement those components, their structure and interrelation, the interfaces and interactions between them,
- their communication schemes and their lifecycle procedures, and
- the relation and interactions of the system with external elements in the environment.

In that way, each i4Q technical solution will have in consideration all those previous aspects. These elements are coordinated by activities (usage viewpoint) and supportive of the system capabilities (business viewpoint).

The i4Q implementation viewpoint will describe:

- General architecture of the i4Q IIoT system: its structure and the distribution of components, and the topology by which they are interconnected;
- A technical description of its components, including interfaces, protocols, behaviours and other properties;
- An implementation map of the activities identified in the usage viewpoint to the functional components, and from functional components to the implementation components; and
- An implementation map for the key system characteristics.

Based on the business viewpoint of the i4Q Pilots, and taking into account their specific requirements and objectives, in the implementation viewpoint we could use some architecture patterns proposed for IIoT, implementations with the goal of identifying some common, typical and essential features of IIoT systems. Some of the well-established architectural patterns, being the first the most important, are:

- Three-tier architecture pattern: that comprises edge, platform and enterprise tiers. These tiers play specific roles in processing the data flows and control flows involved in usage activities, and they are connected by three networks, proximity, access and service network, as shown on **Figure** *28*.
- Gateway-Mediated Edge Connectivity and Management architecture pattern
- Layered Databus pattern.

Figure 28. Three-Tier IIoT System Architecture network connections (IIC, 2019)

6. Conclusions and Next Steps

This deliverable deals with the first release of the i4Q Reference Architecture, based on the project vision. The design of the i4Q RA will be an iterative and parallel process, in which the results provided by several activities will be gathered and included in a systematic project vision.

During the next months, this task of providing a final RA version will be performed in parallel with those of its viewpoints. Viewpoints will offer a framework to think iteratively through the architectural issues that may arise during its conception. So, the analysis across the four key viewpoints (business, usage, functional and implementation) will serve as input for the architecture, which at the same time will influence them (T2.3 – T2.4 – T2.5 – T2.6). The combination of the results obtained from the different viewpoints will be derived into a detailed reference architecture. Results will include: business, regulatory and stakeholders' key inputs (from business viewpoint); an identification of tasks, roles or activities to be performed by the framework (from usage viewpoint); a decomposition into its Control, Operations, Information, Application and Business domains (from functional viewpoint); an identification of associated flows and an analysis and selection of the technologies required for its implementation (from implementation viewpoint).

Another key input will be the definition of the digital models and ontologies to be used in the i4Q Framework (T2.2). The analysis performed in D2.2 will represent the basis for a mapping activity in order to establish the best data models and ontologies for each architectural tier.

The definition of the second version of the RA will also take into account all the considerations that will be formalized in the description of the use case scenarios and the requirements collection (T1.3 and T1.4); special attention will be paid to the needs emerging from the pilots.

The operational needs will help to better identify a RA representing a valid input for the implementation activities: WP3 - Reliable Industrial Data Services Infrastructure - dealing with methodologies, tools and infrastructure to ensure the necessary data quality; WP4 - Big Data Services - dealing with data integration and fusion for analytics and simulation models; WP5 - Manufacturing Line Qualification and Reconfiguration – dealing with strategies and methods for process qualification and optimization.

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8. Appendix I

Type	Name	Brief description	Reference technologies	Status (e.g. WIP, PoC, consolidated version, on going initiative, ...)	Website/Repository	Why it is interesting (why it makes sense to consider it for our i4Q analysis)	How we will use it	How we are contributing or planning to contribute to it
Project	QUALITY	Digital Reality in Zero Defect Manufacturing	High-Performance Computing (HPC), Digital Twin, Virtual/Augmented/Mixed Reality, Big Data and AI, IoT	On going	https://qu4lity-project.eu/	Digital Manufacturing Platform interoperability, standards and security	Many enablers developed or customised will be made available through the marketplece	exhange of information, vision
Project	ZDMP	An extendable platform for supporting factories with a high interoperability level to cope with the concept of connected factories to reach the zero defects goal.	IIoT, Big Data and AI, Digital Twin, Non-Intrusive Inspection, Process and Product quality control, Docker containers, Rest APIs, Message Bus...	On going	https://www.zdmp.eu/	Digital Manufacturing Platform interoperability, standards and security	Many enablers developed or customised will be made available through the marketplace	exhange of information, vision
Project	vf-OS	Open Operating System for Virtual Factories, composed by a Virtual Factory System Kernel (vf-SK), a Virtual Factory Application Programming Interface (vf-IO), a Virtual Factory Middleware (vf-MW), an Open Applications Development Kit (vf-OAK) provided to software developers for developing Manufacturing Smart Applications (vApps) for industrial users, using the vf-OS Studio, and then to deploy those vApps in the Manufacturing Applications Store (vf-Store) in the Virtual Factory Platform (vf-P)	Visual development technologies (JavaScripit, WebGl, etc), Windows Azure Service Bus, Big Data and AI, IIOT, Rest APIS...	Finished	https://www.vf-os.eu/	Digital Manufacturing Platform interoperability, standards and security	Provide an application market focused in factory	exhange of information, vision
Project	C2NET	Cloud Platform for supporting the SMEs supply network optimization of manufacturing and logistic assets based on collaborative demand, production and delivery plans	IoT, Big Data, Cloud platform	Finished	http://c2net-project.eu/		provide a scalable real-time architecture, platform and software	exhange of information, vision
Project	IoTwins	Big Data platform for optimized and replicable industrial and facility management	IoT, Big Data, Cloud/Edge Platform	On going	https://www.iotwins.eu	Platform interoperability, security		exhange of information, vision
Project	BOOST4.0	Boost 4.0, starting 1st January 2018 and with a duration of 3 years, is the biggest European initiative in Big Data for Industry 4.0. With a 20M€ budget and leveraging 100M€ of private investment, Boost 4.0 will lead the construction of the European Industrial Data Space to improve the competitiveness of Industry 4.0 and will guide the European manufacturing industry in the introduction of Big Data in the factory, providing the industrial sector with the necessary tools to obtain the maximum benefit of Big Data.	Big data, IoT, Process and Product quality control, AI, human-AI collaboration	Finished	https://boost40.eu/	Contribution to the solutions to be adressed under WP4 "Manufacturing Data Analytics for Manufacturing Quality Assurance"	Provide the infrastrucutre and big data services for big data processing and visualizations	TBD
Solution	IKERLAN KONNEKT	360º solutions for industrial digitalization	Digitalization Cybersecurity IoT Artificial Intelligence	On going	https://www.ikerlan.es/en/ikerlankonnekt			

Figure 29. i4Q Survey for Projects and Solutions