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DIGITAL MANUFACTURING PLATFORMS FOR CONNECTED SMART FACTORIES

D6.2 ZDM Experimental Facilities and Testbeds (Final version)

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Partner(s) contributing :	CEA, AIC, IntelliMech

Abstract: This deliverable presents the different ZDM experimental facilities and documents the upgrades that have been completed, that are on-going, and that are planned for the near-future.

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Contents

HISTORY

Version	Date	Modification reason	Modified by
0.1	10/11/2020	First draft	Michael BOC
0.2	04/01/2021	Integration of each contributions	Michael BOC
0.3	02/04/2021	Integration of JSI TEF description	Michael BOC
0.4	11/06/2021	Integration of FFLOR TEF description	Michael BOC
0.5	18/06/2021	Final version	Michael BOC
1.0	30/06/2021	Final version after review process	Michael BOC

Executive Summary

This deliverable "D6.2 ZDM Experimental Facilities and Testbeds (Final Version)"of the QU4LITY project documents the enhancements and upgrades that operated, that are ongoing, or at least planned for the reminder of the project.

As described in the Grant Agreement: "*This task will be devoted to the establishment of world-class experimental facilities for ZDM products and processes. The starting point will be existing facilities of the project partners such as CEA's FFLOR experimental platform, which includes a wide range of measurement tools (e.g. for product conformity test), along with facilitates for easily connectable/reconfigurable communications devices and AI-based tools for understanding the whole production chain behaviour. Additional experimental facilities will become accessible through the BeInCPPS project (i.e. and its CPPS testbeds), but also through the DIH of the project. Existing testbeds will be documented in terms of their capabilities and will be customized to the needs of ZDM/AQ processes. Throughout the duration of the task, the experimental facilities will be augmented with new software and devices in order to broaden their testing and validation capabilities*."

The different Technical Experimental Facilities (TEFs) participating in the project are engaged to participate in the tests and validation of the technical contributions. Such participation could lead to upgrades in TEF equipment to support such testing/validation, to complement scenarios, and/or to implement partially/completely the QU4LITY ZDM reference architecture to support future experimentations.

This deliverable is the final version that describe such process. The first version (delivered at M12) has been the opportunity to describe the TEFs, the available setups and equipment that technical providers have considered to select where to run intermediate/final experiments. In this final version, we report the evolution that those TEFs have considered by participating in this project.

1. Introduction

1.1 Scope and purpose of the Deliverable

One of the main goals of the QU4LITY project is to adopt a practical, experimentation-based approach for ensuring standards-compliance for its development. However, European manufacturers, solution providers and innovators are not offered with access to experimental facilities and testbeds, which could allow them to conduct experimentations and certify innovative Zero-Defect Manufacturing (ZDM) technologies. To address this challenge, QU4LITY project will setup testbeds and experimental facilities based on the standards-based reference architecture of the project and on top of the world class facilities that will be contributed by the project partners (e.g., CEA, Fraunhofer, JSI). Accordingly, it will enhance these facilities with tools, techniques, processes and other complementary assets (such as training and support). The testbeds will become accessible to all stakeholders of the QU4LITY digital manufacturing ecosystem, in order to facilitate manufacturers and providers of industrial solutions to learn, experiment and innovate in ZDM/Autonomous Quality (AQ), but most important in order to facilitate testing of compliance to standards and relevant certification processes. Therefore, the main objective of WP6 is to establish and provide the ZDM experimental facilities of the project, which will support all work packages that deal with digital enablers and enhancements for ZDM (i.e. WP3, WP4 and WP5) to test, certify and ensure the standards compliance of their developments.

The task T6.1 is devoted to the establishment of world-class experimental facilities for ZDM products and processes. The starting point is the existing facilities of the project partners such as CEA's FFLOR experimental platform, which includes a wide range of measurement tools (e.g. for product conformity test), along with facilitates for easily connectable/reconfigurable communications devices and AI-based tools for understanding the whole production chain behavior. This first version of deliverable D6.1 lists the existing experimental facilities of QU4LITY partners. It provides for each facility their capabilities, what it can provide as measurement tool and technical enabler for QU4LITY partners in order to allow them to use and test their solutions in these facilities.

This deliverable is the second and final version, which reports the presented actions. The scope is to present the evolution in terms of upgrades and enhancements of equipment, tools, and processes deployed (or planned) to support the project experimenters and OpenCall winners.

1.2 Relation of T6.1 to other tasks

T6.1 is part of WP6 "Experimental Facilities for Testing, Verification, Certification and Standards Auditing", which interacts between experimenters from WP3, WP4, WP5 and Experimental facilities contact points.

As depicted on Figure 1, WP6 works in combination with WP7, which covers the pilots. As such, experimental facilities can be fully involved in WP7 for specific pilots. In such a case, WP6 keeps track of the enhancement and upgrades ran at these TEFs.

If globally WP6 interacts with technical workpackages WP3, WP4 and WP5, T6.1 focus its activities on promoting Qu4lity architecture and experimentations directly with the TEFs.

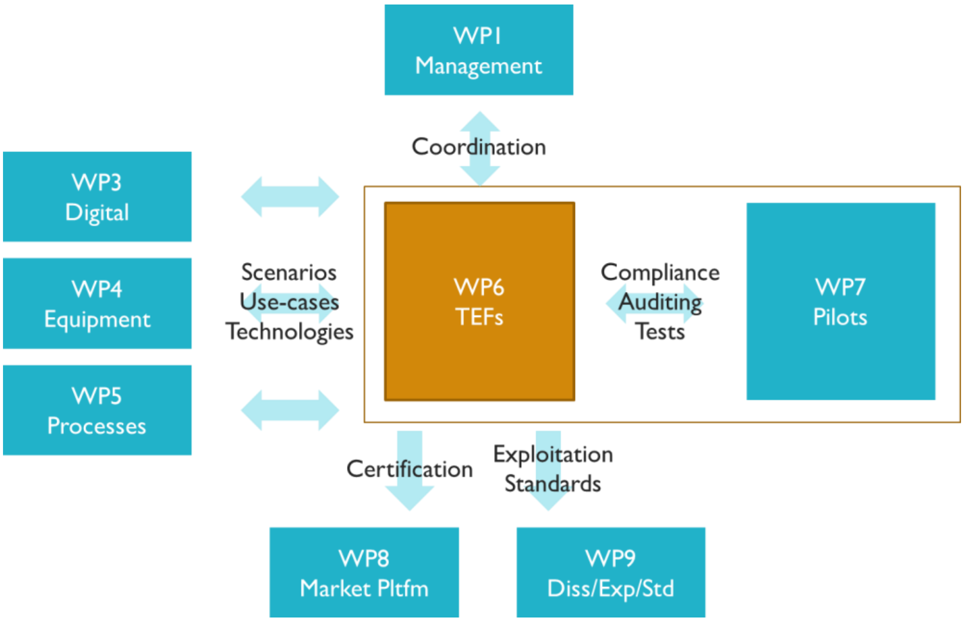

Figure 1: Workpackage structure of the Qu4lity project as centered on WP6

WP6 consists of tasks as described in Tableau 1.

Tableau 1: Overview of Tasks and deliverables in WP6

Task	Description	Period	Deliverables
6.1	Testbeds Analysis, Customization and Continuous Upgrade	M1-M24	D6.1 (M12) D6.2 (M24)
6.2	Digital Infrastructures Verification and Certification	M8-33	D6.3 (M15) D6.4 (M39)
6.3	Digitally Enhanced ZDM Equipment Verification and Certification	M8-M33	D6.3 (M15) D6.4 (M39)
6.4	ZDM Processes Deployment and Testing	M8-M33	D6.3 (M15) D6.4 (M39)

Task	Description	Period	Deliverables
6.5	Compliance Testing and Auditing against ZDM & Cognitive Manufacturing Standards	M12-M39	D6.5 (M18) D6.6 (M39)
6.6	Testbeds Support Services and Integration of Open Calls Results	M15-M39	D6.7 (M18) D6.8 (M39)

1.3 Document Structure

This deliverable is composed of the following main parts:

- **Technical experimental facilities:** This section presents an overview on the 8 TEFs that are part of the consortium.
- **Enhancement & upgrades:** This section provides the list of the available measurement tools per experimental facility that may be used to validate technical contributions. This includes measurement equipment as well as datasets.
- **Conclusion:** This section will summarize the work performed by the partners targeting the Testbeds Analysis, Customization and Continuous Upgrade inside the QU4LITY project. It will additionally describe the future work to be performed inside Task 6.1 in order, for the experimental facility, to be identified as a world-class experimental facilities for ZDM products and processes and to be able to perform audit and certification of processes and equipment.

2. Technical Experimental Facilities (TEFs)

This section presents an overview of the eight TEFs that participate in this initiative. The first version of this deliverable has focused on describing the equipment and tools available at those facilities. Those details will not be covered again in this final version. However, it is important to recall the situation, resources and expertise provided by those TEFs.

As depicted on Figure 2, one can appreciate visually the location of the TEFs active in the Qu4lity ZDM activities.

Figure 2: Europe map of the eight TEFs facilities location.

The following is, for each TEF, a one-page overview of its global activities:

FFLOR (CEA)

The CEA Tech FFLOR platform proposes a global view of the Factory of the Future by centralizing human and materials means in a same place. The platform provides access to high added-value technologies.

Covering a surface of 1000m², FFLOR objectives are to test, develop and validate new concepts dedicated to flexible factory and create an industrial network with end-users, startups, techno providers, system integrators and research laboratories.

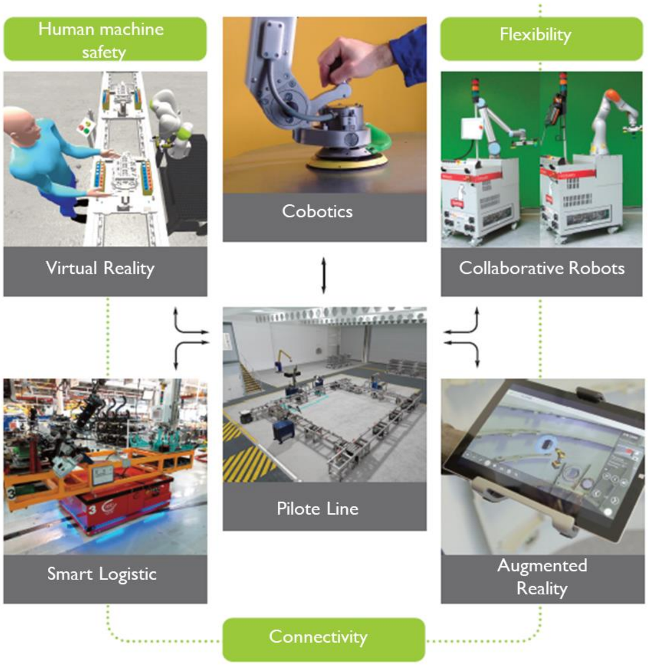

Figure 3: activities in FFLOR platform

The activities are centered around 5 themes:

- Virtual Reality / Augmented Reality
- Collaborative robots
- Cobots
- Smart logistics
- Systems Connectivity and interoperability

The CEA FFLOR platform is located at the heart of the PSA factory of Tremery (first engine factory of PSA group in terms of production), in Lorraine, France.

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ARENA 2036 (Fraunhofer IPA)

The University of Stuttgart together with Fraunhofer IPA and further partners have established the research campus ARENA2036 (Active Research Environment for the Next Generation of Automobiles https://www.arena2036.de/en/). This research campus develops competitive production models for a flexible factory of the future in 2036, the 150th anniversary of the automobile. Lightweight materials such as fiber composites can then be handled in serial production as effectively as aluminum and steel today.

The research campus is designed as a support instrument. It bundles research activities and competences from university and industry in one place. Scientists from universities, non-university research institutions and industry work under one roof. The research campus does middle and long-term research on this specific topic with a special focus on application-oriented basic research. The research factory is an integration platform, meant as experimental field for new methods for the manufacturing and assembly of lightweight vehicles. It continuously transfers the results into other industries.

Figure 4: research and production floor at ARENA2036

Basic information:

- Research space of about 10.000 m²
- Up to 160 fulltime employees
- Funded with more than € 30 Mio. of state and EU-Funding (EFRE)

Features:

- Up-to-date building technology
- Versatile and adaptable infrastructure
- Modern, attractive and flexible working environment for the Factory 4.0

Address: ARENA2036, Pfaffenwaldring 19, 70569 Stuttgart, Germany

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Industry4.0Lab (I4.0Lab) (POLIMI)

Historically, Industry4.0Lab (https://www.industry40lab.org/) or I4.0Lab was called FoFLab. It is located in the School Of Management of Politecnico di Milano. It is a tangible physical entity to carry out research activities in a "real-like" Industry4.0 environment. I4.0 Lab represents a central pillar for Industry 4.0 awareness and knowledge diffusion, both for industrial network and for research and academic network.

I4.0Lab is an effort toward a multidisciplinary vision of production environments for the realization of a "teaching factory" for educational and research purposes. In fact, I4.0Lab creates the environment for cross-learning from national and international universities, visiting research exchanges, joint projects and long-term collaborations.

I4.0Lab is a Didactic Factory based on FESTO technology to provide a hands-on I4.0 facility for both students and SMEs. The Manufacturing EcoSystem where it is positioned includes 3 major dimensions to consider: the **human factor**, the **product** and the **process/plant**.

Figure 5: Overview of Industry4.0Lab

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Automotive Smart factory ASF (AIC)

Automotive Smart Factory - ASF is the first advanced manufacturing competence centre, conceived to provide a comprehensive service to accompany the European automotive industry in the implementation of the manufacturing of the future.

Figure 6: ASF facility

In this sense, ASF accompanies each company throughout the transformation process, adapting itself to its particular needs, from the development of personalized strategies, the evaluation of the impact of the implementation of these strategies, to the actual implementation in the factory. For all these reasons, it is covering research projects, engineering services or the training of people at different levels.

For this, ASF combines physical and virtual capabilities in the same space which makes it ideal for analyzing the different technologies associated with advanced manufacturing or industry 4.0. Digitization in this case, is largely given by the virtual part (Manufacturing Intelligence), which includes an intelligent manufacturing system that monitors and manages the processes in real time to ensure zero defects through the domain of the process and to achieve unit traceability with information relating to the process among others. To make this possible, the lines of research related to digitalization are, among others, big data, active monitoring of the state of the equipment, intelligent process management, advanced machine-to-machine communication systems, simulation of processes and control systems, digital quality management, human-machine interaction, etc.

The physical workspace includes cutting edge equipment, such as a stamping servo-press, an arc-welding cell and different control and in-line verification systems. It serves as a technology demonstrator.

The virtual workspace consists of a Smart System that manages the manufacturing process with an integral approach

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SMACC (VTT)

SMACC is an ecosystem where the essential research action is a strategic partnership between TUT (Tampere University of Technology) and VTT Technical research center of Finland. SMACC relies on a novel and agile operation model, which enables the efficient integration of SME oriented service culture and the highest scientific competence in smart machines and manufacturing area. Fast piloting and easy access to infrastructure enables the dissemination of enthusiasm and courage for new innovations.

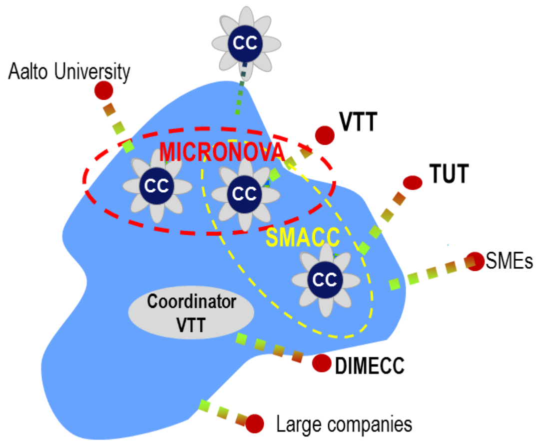


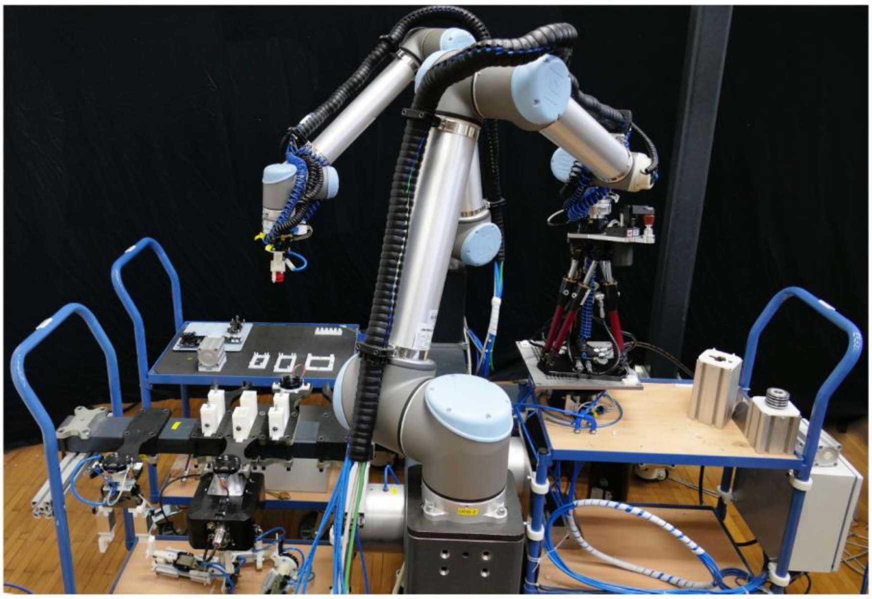
Figure 7: Smart Manufacturing Digital Innovation Hub (DIH) in Finland

Services:

- Pilot line / demonstration line / scale-up and pre-series
- Full-scale production modelling, simulation and planning. Order and delivery process development
- Proofs of concept and Lab testing of basic experimental set-up for e.g. machine and production systems, robotics and automation and IoT
- Prototyping (integrated system/ sub-system) development & testing
- Scientific & technological development
- Product validation, certification and characterisation
- Study / initial design / Simulation
- Ecosystem building, program and project services, co-creation, international networking
- Visioning and Strategy Development for Businesses
- Digital Maturity Assessment
- Education and skills development
- Market intelligence
- Incubator/accelerator support

Address: SMACC in located in University of Tampere campus area in Hervanta

Contact: Helin Kaj (Kaj.Helin@vtt.fi), Juha-pekka Anttila (Juha-Pekka.Anttila@vtt.fi)

JSI Facility(JSI)
Reconcell workcell is a reconfigurable robotic assembly workcell that uses flexible, reconfigurable and modular concepts to efficiently manage changeable production. It is a stand-alone robotic workcell at Jozef Stefan facilities, where it can be readily used to test concepts of rapidly reconfigurable production. The workcell periphery is modular. Various peripheral elements can be added to the cell with the Plug and Produce (PnP) connectors. The developed PnP connector also provides electrical power, Ethernet connection for data transfer, and pneumatic lines, which can all be used by the equipment contained within the module. This in turn enables the hardware modules to be completely self-sufficient and ready to provide the desired functionality as soon as they are coupled to the main frame. Various peripheral elements are readily available: passive hexapod fixtures, passive linear units, robotic screwdriver with exchangeable screw bits, rotary table, pneumatic vise jaws, power over Ethernet servo gripper, Spacer gun, etc. The workcell in an assembly configuration is depicted in Figure 8.  Figure 8: Workcell in an assembly configuration at JSI
Address: The platform is located inside the JSI facilities, at the Department of automatics, biocybernetics and robotics. Jamova cesta 39, 1000 Ljubljana, Slovenia
Contact: Andrej Gams (andrej.gams@ijs.si), Aleš Ude (ales.ude@ijs.si)

SmartLab (IntelliMech)
SmartLab is a demonstrative laboratory where different machines of consortium's companies are connected together, following principles of Industry 4.0 paradigm. The laboratory is divided in two main areas: the "software room", where researchers can develop software or use it for simulation and testing, and the showroom, where some of the demonstrators developed in the last years are shown. In particular, these demonstrators are: • A remote maintenance tool for machines providers, developed on the Indeva Liftronic manipulator. • A monitoring system for machines vendors, developed on assembly line provided by Cosberg. • A prognostic system for circuit breaker, developed on ABB device. • A SCADA for textile looms, developed for Itema.
Address: SmartLab is located inside POINT, the Technological Innovation Center of Bergamo. POINT is located in Dalmine, in province of Bergamo, close to the faculty of Engineering of Bergamo
Contact: Valerio Pesenti (valerio.pesenti@intellimech.it), Stefano Ierace (stefano.ierace@intellimech.it), Davide Pasanisi (davide.pasanisi@intellimech.it)

ROSF
The Region of Smart Factories (RoSF) is one of the flagship projects of the Northern provinces in the Netherlands. The RoSF consortium was established around the main three original equipment manufacturing companies; Philips, Fokker and TenCate, but has since grown into a group of thirty partners (SMEs, knowledge institutes and education institutions). RoSF has the status of Field Lab on the national Smart Industry Action Agenda. The aim of the Region of Smart Factories is to develop the Northern Netherlands into the home of Smart Factories, thereby laying the foundations for a strong manufacturing industry (HTSM, 2016). The RoSF activities focus on: • Product development: from trial & error to first time right; • Manufacturing: from 'casting everything in concrete' or 'selling no' to flexible manufacturing and coping with everyhting; • Business development: valorisation of know-how. Three pilot projects will be implemented: • Smart Production Lines (developing faultless production processes); • Design of Smart Factory (optimisation of know-how); • Customised Manufacturing (enabling customised production). And two toolboxes: • Rendering existing processes; • Optimising existing design processes.
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3. Enhancement & upgrades

In this Section, we report the enhancement and upgrades that have been performed and that are ongoing on the TEFs.

3.1 Automotive Smart factory ASF

ASF is a living testbed, designed to simulate and validate 4.0 concepts, digital architectures and services for the industry. New applications and uses cases are emerging and require high-performance real-time response: applications such as autonomous control, augmented reality, virtual reality or new services for industries need different network requirements.

In this regard, AIC aims to be the first industrial platform to integrate Edge Computing technology as an opportunity to explore potential benefits of this new network architecture. This edge computing integration into AIC solution will enable edge environment for industrial services. Some of the benefits can be reflected in an increased and scalable data analysis capacity, production flexibility and implementation of highly demanding real time data demanding virtual platforms of high requirements.

Moreover, AIC also aims to be the first industrial platform to integrate 5G connectivity, which could potentially provide a new capability for testing cloud deployments as local native applications, hybrid cloud solutions with real time data processing through WAN connections or centralized and replicable tasks execution among other potential benefits.

The ASF-Automotive Smart Factory Experimental Facility will upgrade towards its infrastructure to enhance capacities and validate potential technologies related to communications and applications development in an industrial environment.

This Enabling Technologies will bring new capabilities that are highly applicable to the industrial sector.

- **Enhancement/upgrade description**

In collaboration with Telefonica and Innovalia, the upgrade of the Technical Experimental Facility will focus on the integration of Enabling Technologies for the virtualization of industrial operations made remotely and in real time. In this regard, 5G capabilities and edge computing will be used to virtualize environments with cutting edge equipment and to be able to control it reliably, safely and in real time.

The use-case provided by Innovalia will allow to validate a real industrial scenario where highly demanding computing requirements are needed. Telefónica will provide the ASF with high computing capacity to join the virtual and the real world.

In this respect, AIC aims to be the first industrial open platform to integrate Edge Computing technology and 5G connectivity in its ASF infrastructure as an opportunity to explore potential benefits of these new network architectures

Technologies & infrastructures:

- OnLife Edge Computing platform & 5G Connection to datacenter

Real time processing is key within the factory to be efficient and have complete control of the factory situation, operations and processes, which allows real time decision making. Edge Computing will bring the data storage and processing capacity close to the ASF by having the real capacity in the Telefonica infrastructures without the large investment and scalability issues it entails to do it locally. Edge computing proximity to the factory enables very-low latency services for real time and high demanding applications in the factory.

ASF network potential architecture to-be scenario is depicted in Figure 9. The edge computing servers will be deployed within this network and connected to Telefónica's data centre through a 5G connection. Therefore, Innovalia's quality lab equipment will be upgraded to be able to support 5G connectivity.

The 5G portable infrastructure will be connected to the Central Firewall, so to enable both public 5G scenarios and private networks, which are similar to current LTE enterprise private services.

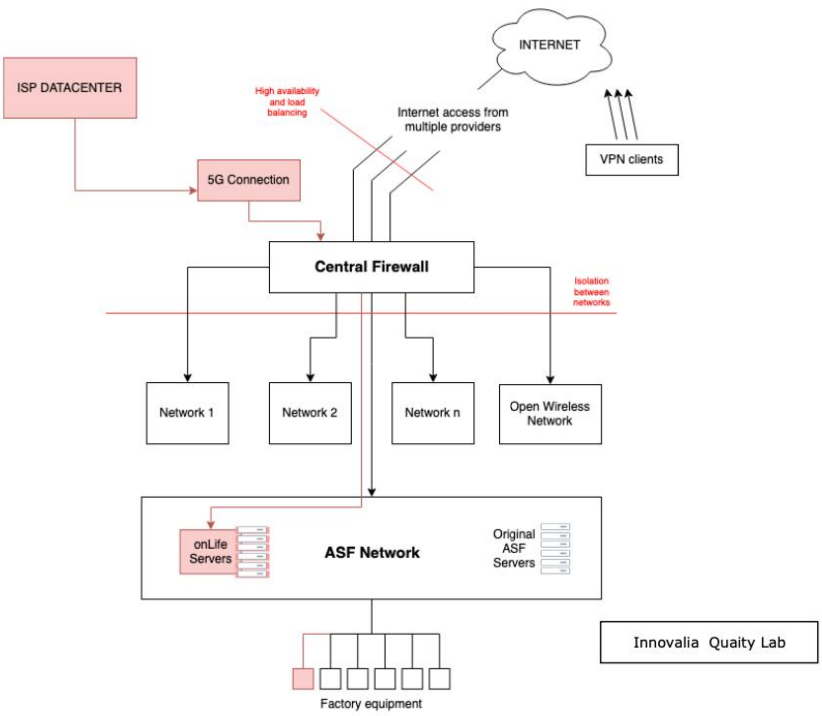

Figure 9: ASF network potential evolution

Specific software and hardware will be installed at the ASF to integrate the enabler technologies and be able to provide the infrastructure for the use-case validation:

- ***Software***

OpenNebula is an open-source, Apache-licensed, and enterprise-ready cloud management platform providing IaaS private, public and hybrid clouds management. OpenNebula allows managing heterogeneous distributed data centre infrastructures.

It was started as a research project in 2005, aiming to create efficient solutions for virtual machines management on distributed infrastructures, allowing high-level scalability. OpenNebula was first released on 2008. It has matured through more than 100 open-source releases and more than 10 years of research leading to the publishing of 5.10 release in December 2019.

OpenNebula provides features at two main management layers:

- Data Centre Virtualization Management: OpenNebula provides advanced features like capacity management, resource optimization, high-availability and business continuity. It directly integrates with hypervisors, such as KVM, and containers, like LXD, to rule complete control over virtual and physical resources.

- Cloud Management (Virtualized Infrastructure Manager - VIM): OpenNebula also provides a multi-tenant, cloud-like provisioning layer on top of virtual infrastructures, including integration over existing infrastructure management solutions like VMware vCenter. It provides provisioning, elasticity and multi-tenancy features including virtual data centres (VDC) provisioning, data centre federation and hybrid cloud computing to connect in-house infrastructures with public clouds.

The following OpenNebula features had been key to select it instead of other VIM alternatives:

- Lightweight and easy to install,
- Easy to extend features through REST APIs,
- Allows services creation with configured and parametrized images which are
- stored locally, ready to use, allowing a shorter boot time,
- Uses VLAN tags to mark traffic, simplifying the network interconnection
- between VMs,
- Includes an internal monitoring and alert system based on metrics gathered
- by OpenNebula, allowing triggering scalability rules or alerts.

- ***Hardware***

OnLife Edge computing platform will leverage AIC's existing physical networking devices and connectivity within ASF and Innovalia Telemetry laboratories. The virtualization infrastructure manager (VIM) will host the applications described in the next sections. The physical infrastructure is composed by two dedicated servers installed within current AIC's datacentre, with the following technical specifications:

- 2x AMD EPYC 7302,
- 192 GB RAM,
- 2x 800W power units,
- 4x integrated Gigabit Ethernet,
- 2x SFP+ 10Gbit PCIe,
- 4x 1 TB SSD disks.

An existing L2 switch with up to 16 SFP+ ports will be used to connect the 4x10G ports of each server.

Figure 10: Qu4lity dedicated servers

- Services (Open call or other)

These new technologies will allow us to respond to the demands of the industry such as, cost-effective, smart, scalable and sustainable factories of the future.

The ASF will have the power to provide the service of technology demonstration and integration for validation scenarios of different stakeholders of the industry.

- **Current and planned experimentations**

Thanks to its modular design and scalability, the ASF will integrate Innovalia's quality lab within its infrastructure. Thus, adding value to the process and validate ZDM quality assurance process of automotive parts with edge computing and 5G technologies. The experimentations planned are oriented to the Innovalia use-case: Connected Worker Remote Operation.

The Connected Worker Remote Operation of Quality Equipment scenario consists of enabling real time remote operation of the Coordinate Measurement Machine (CMM). This means the metrology expert will be able to configure the CMM located in the manufacturing site from the Innovalia headquarters, saving time and money by reducing travel or delivery of parts.

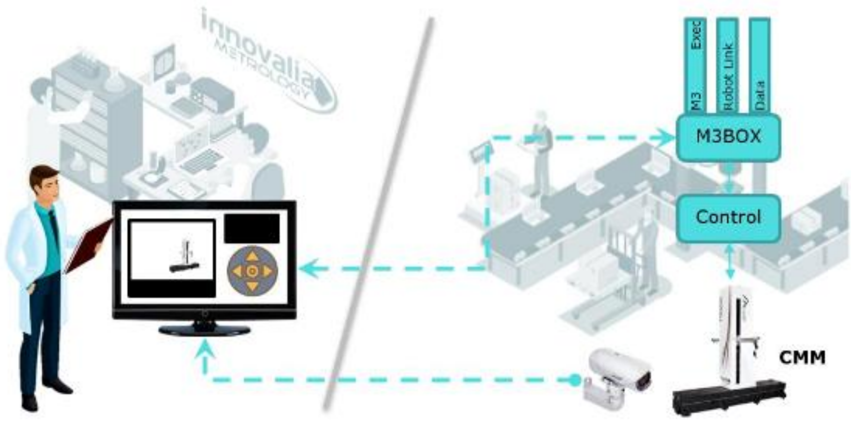

Figure 11: ASF use-case

Figure 11 shows a representation of the Connected Worker Remote Operation use case. The production line is located on the right, where CMM machine and its controller are connected to M3BOX, an edge device provided by Innovalia. M3BOX comprises three main software services essential to operate the CMM:

- **M3ExecutionEngine**: This module stores the inspection program,
- **RobotLink**: Module used to manage the machine itself. It primarily manages the movement of the arm that holds the sensor in 3 axes,
- **DataAssembler**: Management module for the operation of the optical sensor. It enables setting the camera resolution and turning it on and off. On the image, the camera represents the video streaming from 2 different cameras:
  - General camera: provides a general view of the piece,
  - Detail camera: small camera attached to CMM sensor for detailed inspection of the target zone being scanned. Detail camera enables remote checking from the local site to Innovalia's premises, on the left, where metrology experts have an interface to see real-time video streaming while the machine is controlled with a virtual joystick.

The main objective is to demonstrate the benefits of using 5G services and Edge Computing in an industrial environment, enabling a secure and independent channel to connect to Innovalia's quality control equipment without interfering with the regular operation of the factory where it is installed.

3.2 Industry 4.0

Implementation of a significant environment for implementing ZDM concepts, required to leverage previous technology and methodology experiences done at the Lab, but utilizing components from Qu4lity research activities in the overall framework of the Reference Architecture.

- **Software**

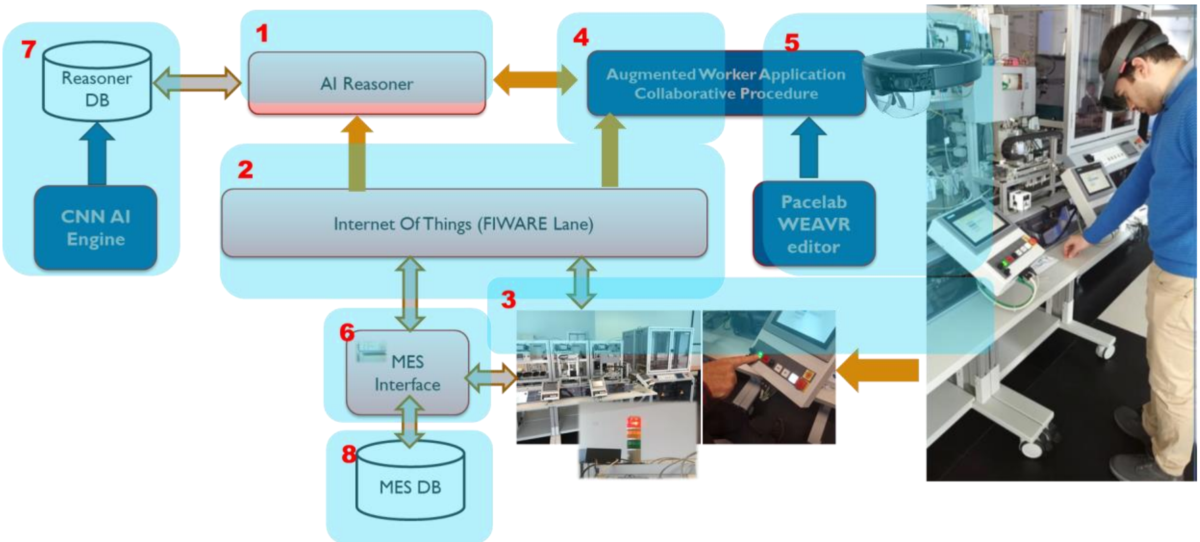

Figure 12 - I40Lab Remote Worker Experimentation Facility Application

The solution consists of the following modules:

1. **Artificial Intelligence Reasoner**: is the application running on POLIMI servers, which receives all events from the IOT, store and process them. Each cycle generates an MQTT message, which contains a complete description of the status of the machine in that specific instant. The reasoned is supporting 2 main functions (see Current status)
2. **IOT Module:** Implementing communication services and implementation of Digital Twin Architecture. At this level are implemented IoT services like semantic annotation, data validation and cleaning.
3. **IIOT module and RealTime control Interface:** sensors set attached to the machinery that can detects any error or malfunction that the machinery had in the previous cycle and send the data to the AI Reasoner. Specific sensors can be added to the process leveraging the AI40A (additive I40 Architecture) approach developed at I40Lab to expand very easily collected data based on implementation needs. Nine different sensor types are nowadays supported (Table 2).

Table 2: Supported sensor types

ID	Name	Description	Type
1	Vibration	Able to capture vibrations up to 44.100 Khz. To catch noise, vibration.	Physical Sensor
2	Gyroscope	Able to capture rotation around 3 axis up to 2000°/sec. To capture rotation or inclination (Sampling frequency up to 200 Hz)	Physical Sensor
3	Temperature	Able to capture temperature and humidity	Physical Sensor
4	Accelerometer	Able to capture accelerations up to +- 4 g along 3 axis (Sampling frequency up to 200 Hz)	Physical Sensor
6	OPCUA sensor	Able to interface OPCUA server to collect in asynchronous way data from line PLCs	Virtual Sensor
7	Video Sensor	Able to capture video frames with RGB resolution of 256x256 pixels	Physical Sensor
8	Virtual Function	Allow to generate an arbitrary signal defined by his generating function of Working Time, Up Time and working Cycles	Virtual Sensor
9	DB collector	Able to extract data from Database and generate an «actualized» signal	Virtual Sensor

4. **Augmented Reality Core:** there is an AR App that runs on the Hololens and can helps the operator with a mixed of 3D and 2D sketches of the specific troubleshooting procedure.
5. **WEAVR Engine:** the AR App manage the process of the procedure thanks to the WEAVR Engine that is the core of the App and made possible the interactions from the status changes of the machine and the operator
6. **MES Interface:** the system is equipped with an Advanced Manufacturing Execution System and SCADA system controlling production. Specific APIs allow to interact with it.
7. **Reasoner DB Knowledge Engine:** The reasoner stores results of the predictions and of the data received from the sensor in a Mongo DB. This DB is also storing models utilized to manage and predict plant behavior and created utilizing CNN (Convolutional Neural Network approach)
8. **MES DB:** The MES use a DB to store data about each station. In that, data related to each single product is stored keeping track of executed operations, duration, energy data and, if any, unplanned event occurred. That can support creation of a virtual image for each product to be utilized to support Product Lifecycle applications.

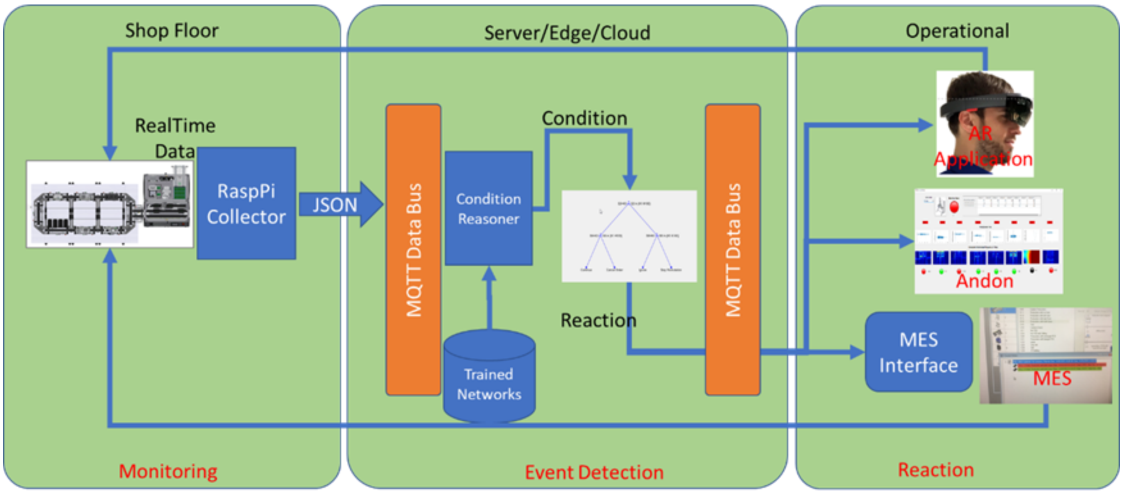

Figure 13 - Condition Detection and DSS

IoT, Digital Twin, Modelling/Learning and DSS functionality are depicted in Figure 13 (They are described in detail in D6.4).

- **Hardware**

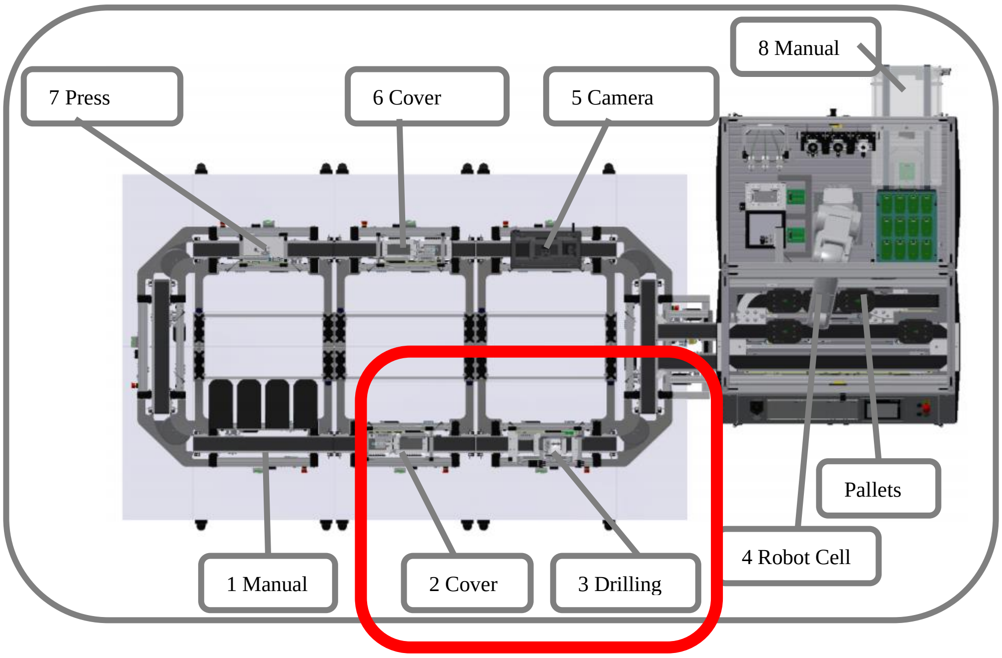

Figure 14 - I40Lab assembly line

The Industry 4.0 Laboratory is made of six interconnected workstation and a robotic arm simulate the production process necessary to build one smartphone.

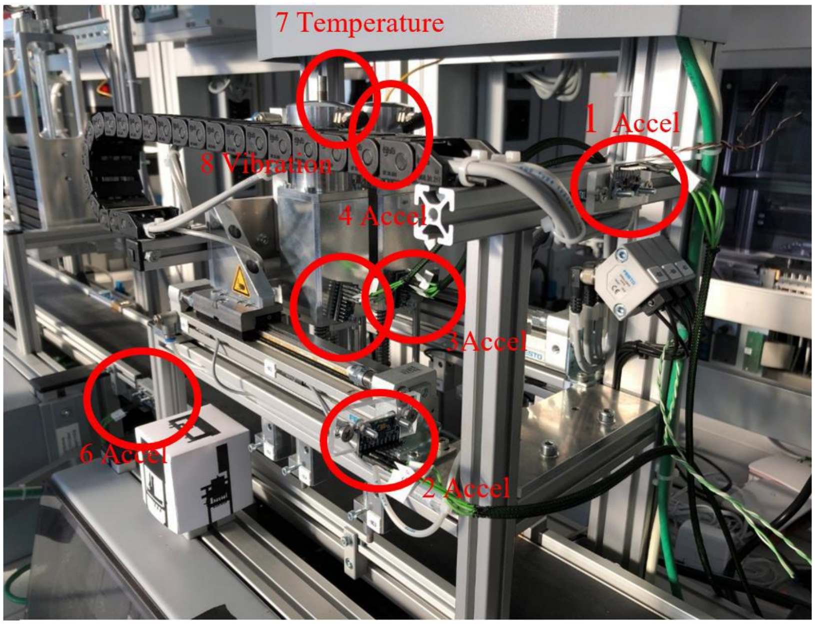

Figure 15 – Extra Sensors

Assembly line stations 2 Cover and 3 Drilling additional sensors are placed to collect further information natively unavailable like vibrations and sounds.

The process includes the collection of real time data from sensors.

Signals from the field are collected by RaspPi bases boxes able to get data directly from OPC-UA modules of PLCs or from sensors connected to the machines.

Time series are converted in JSON messages in the RaspPi and sent as MQTT Messages to the upper level for their analysis

Interaction with user operator is carried out with wearable device: HoloLens

Figure 16 - Hololens

HoloLens is an Augmented Reality devices able to track the space around itself and made a mapping of it, in order to draw a combination of 3D animations and 2D static textual or picture elements that helps anyone is using it to understand better what is the assignment and how to complete it.

Configuration of the AR environment for connection of wearable device, positioning in the shop floor space and definition of the user application workflow is carried out with Pacelab WEAVR (https://pace.txtgroup.com/products/extended-reality/pacelab-weavr/)

- **Services (Open call or other)**

In the following Table 3 are summarized a broad variety of services is able to provide to different stakeholders participating to the Qu4lity ecosystem.

Table 3: Services provided

Service Type	Provided Services
BUSINESS DEVELOPMENT	5
DATA AND AI VALUE CHAIN	7
ECOSYSTEM BUILDING	8
MATURITY ASSESSMENT & SKILLS	6
TECHNOLOGY PROVISION	7
Total Number Services	**33**

A detail description of the services is provided in D6.7 Community Support Services released at PM18.

- **Mapping with reference architecture**

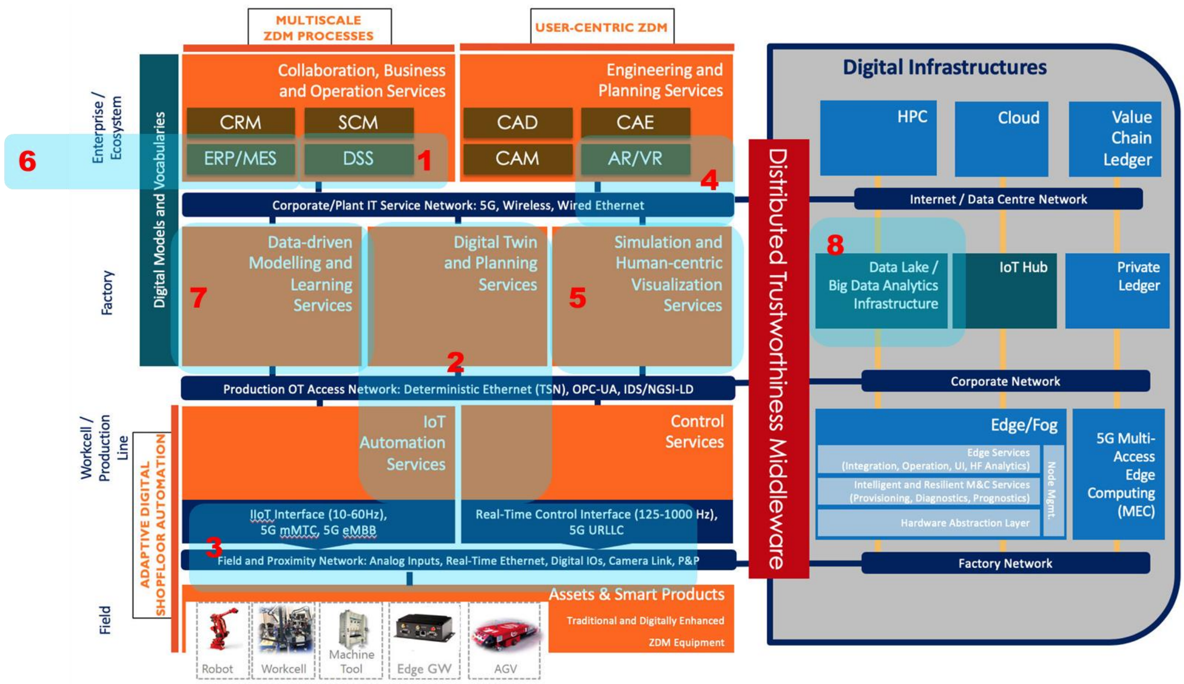

Figure 17 - I40Lab reference implementation mapping on Qu4lity RA

In Figure 17, it is described where specific enhancements developed during experimentation are serving parts of the reference architecture (refer Software page 22).

- **Current status**

Current implementation status is described in detail in D6.3, and it is composed by two main functions.

1. Process Monitoring, event detection and reaction definition
2. Operator activation and support via VR platform

- Process Monitoring, event detection and reaction definition

This process include collection of real time data from sensors (collected and formatted in JSON messages by RaspPi boxes and conveyed via MQTT broker), Analysis by the Reasoner module to identify a specific condition for specific sensor/signal, decision taking to communicate to operational modules (Andon, MES, AR for worker).

- Operator activation and support via VR platform

The human worker is in the factory and has the status of the whole environment summarized in a circle. When there is no problem the circle is green.

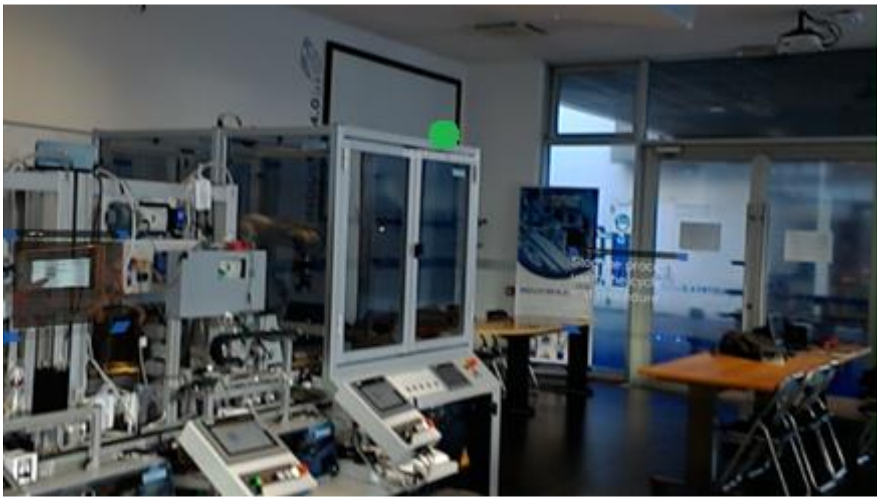

Figure 18 - Starting visualization

When a problem arises, the circle disappears and is substituted by the list of items to work on and can select which one to work on.

Machine Status	Visual message for the operator
Ignore	Info icon with the label "Ignore"
Continue	Info icon with the label "continue"
Cancel order	A Yellow Warning and an audio advice
Stop Workstation	Red critical alarm

- **Planned Enhancements**

- Actions to support interactions with technology providers / openCall winners to integrate foreign environments in a federative fashion
- Connection of part of sensor via 5G infrastructure. Advantage of such solution are:
  - Wireless connection of sensors at high speed, low latency of the data transmission. This can support hard real time application or massive data transmission.
  - Availability of the Edge Computing platform (MEC – MultiAccess Edge Computing) for fast processing close to the plant premises.

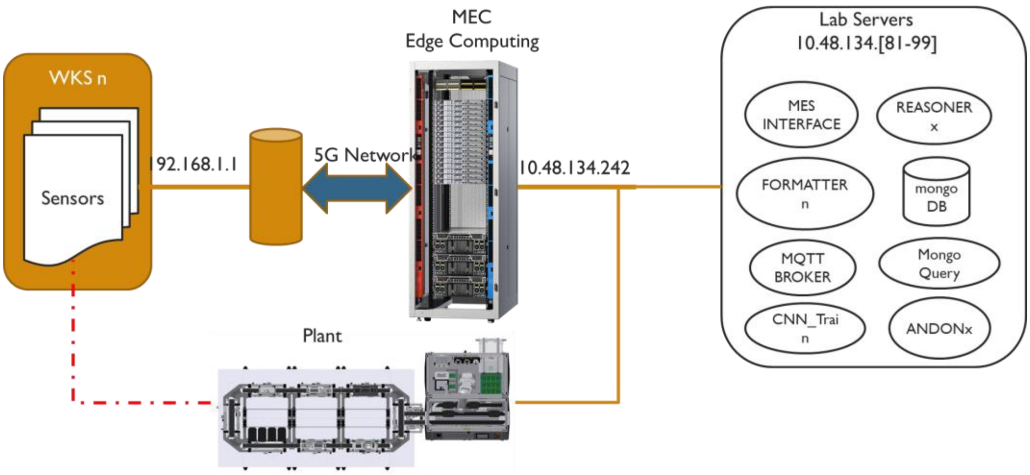

Figure 19 - 5G communication and MEC infrastructure

- Feedback to the historical knowledge base (supporting the decision engine) of all information related to the assistance intervention carried out by the operator. This would allow to enrich the knowledge base and to improve condition management and maintenance planning.
- Improve wearable device based on new technology (e.g. Hololens 2, Magic Leap, …)

3.3 FFLOR

The FFLOR TEF will be upgraded with the necessary infrastructure to support deterministic communication (IEEE TSN – Time Sensitive Network) on top of IEEE Ethernet.

The IEEE TSN working group defines a set of standards and amendments in the IEEE Ethernet specifications, which provide a set of activable mechanisms to achieve high synchronicity (sub-microseconds), bounded latency and strict latency for the different streams. The technology allows differentiated handling of traffic (critical/best effort) that makes it suitable for industrial environments. To this end a specific profile has been defined for this industrial context as well as for other contexts such as automotive, Entertainement, Cellular RAN to name a few.

In the context of Qu4lity and autonomous quality, the determinism of traffic and the high synchronization between the equipment are keys to gain some guarantee on the autonomous processes. For instance, if a remote control of an equipment is needed to compensate deviations, it is required to know exactly when some actions will be executed and if the monitoring is in line with the computation processes.

- **Mapping with reference architecture**

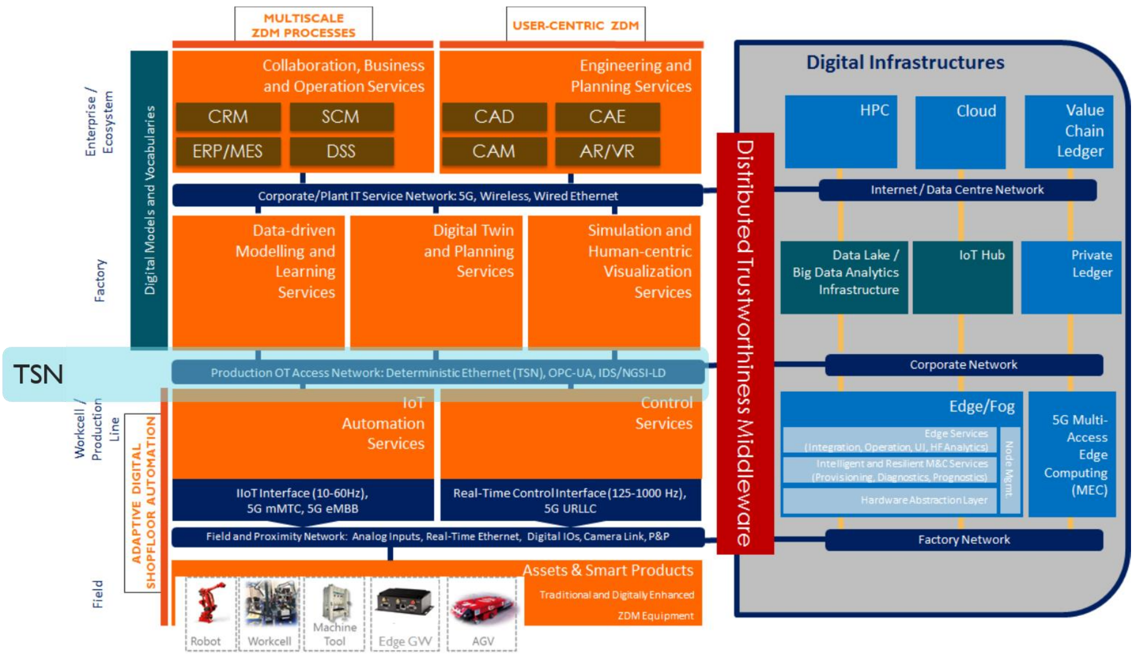

Figure 20: FFLOR reference implementation mapping on Qu4lity RA

The TSN system is presented in D3.1 and D3.2 of WP3.

- **Planned Enhancements**

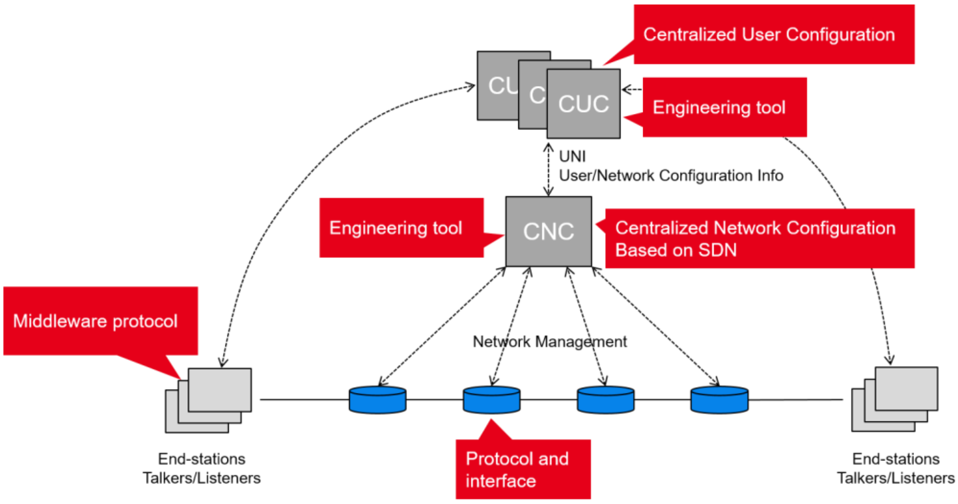

Figure 21: IEEE 802.1Qcc-2018 fully centralized architecture to manage TSN infrastructure.

The planned enhancement of the FFLOR TEF is based on the IEEE802.1Qcc-2018 reference architecture depicted in Figure 21. Each of the element is presented below:

- On one of the production line, a set of two to four TSN switches will be installed to support the interconnection between communicating devices. For demonstration purpose, specific devices will be provided to generate different classes of traffic with different characteristics.
- The TSN switches will be interconnected to a TSN configuration management system developed by CEA in WP4 which is centered around the CNC – Centralized Network Configuration.
- The communicating devices will interact using OPC-UA with the TSN configuration management system (more precisely with a CUC – Centralized User Configuration – entity) to exchange information about network interfaces characteristics, traffic patterns, expected maximum latency to name a few.
- A webserver will be available to interact with the TSN configuration management system for:
  - Designing the traffic that will be accepted in the network knowing the devices that generate traffic (Talkers) and devices that consume traffic (Listeners). This configuration phase is also called "matchmaking".
  - Monitoring traffic performance according to the declared and accepted traffic constraints as well as level of synchronization between equipment

3.4 JSI Facility

As part of the Kolektor pilot, the JSI facility has extended its capability to support the adaptive visual quality inspection functionality.

The Kolektor pilot is composed by a set of equipment around a production line to achieve autonomous detection and removal of defects in injection molding. At the JSI TEF, the adaptive visual quality inspection booth (see Figure 22) has been designed as follow: it is cell in the final part of the assembly line designed to perform a final check of the manufactured product based on a complete visual inspection by a camera handled by a robotic arm that has the ability to target a specific camera viewpoint. In some cases, the robotic arm can be programmatically moved to access specific viewpoint or the manufactured object can be relocated to access those viewpoints.

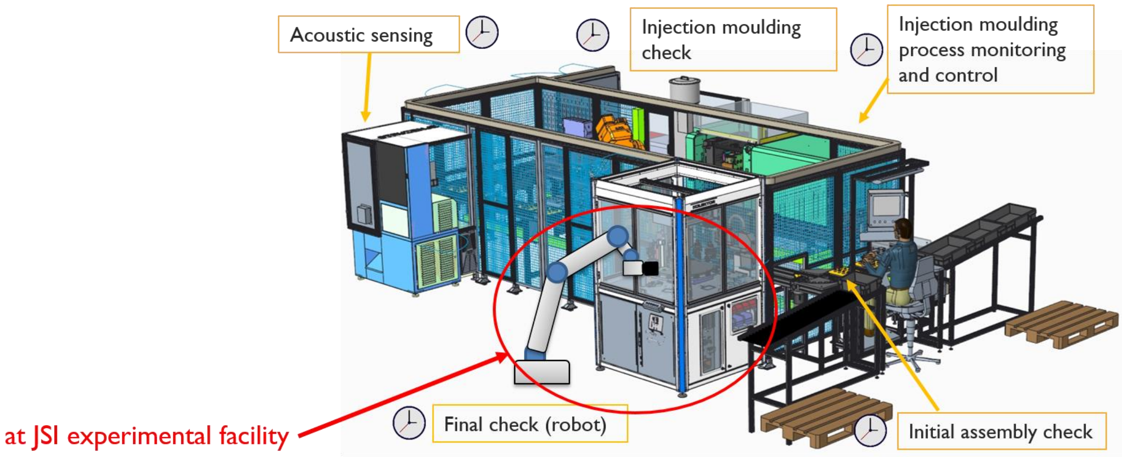

Figure 22: location of the adaptive visual inspection booth on the overall production line for the Kolektor pilot.

- **Software**

The ReconCell software has been extended to support new algorithms for robotic motion. Based on the CAD model of the object, and a set of points of inspection path as input, the software is able to use learning methods to compute the best robotic motion and optimize the robot speed along the specified path based on image quality.

- **Hardware**

The Reconcell workcell has been upgraded to support the targeted usage of adaptive visual quality inspection:

- The ability for the robot to hold a camera (in-hand camera)
- The ability to adapt its position / camera viewpoint to be able to see the required area of the inspected object
- The ability to re-orientate an object with a rotary table
- The ability of relocate the robot if needed (reconfigurable elements)

- **Mapping with reference architecture**

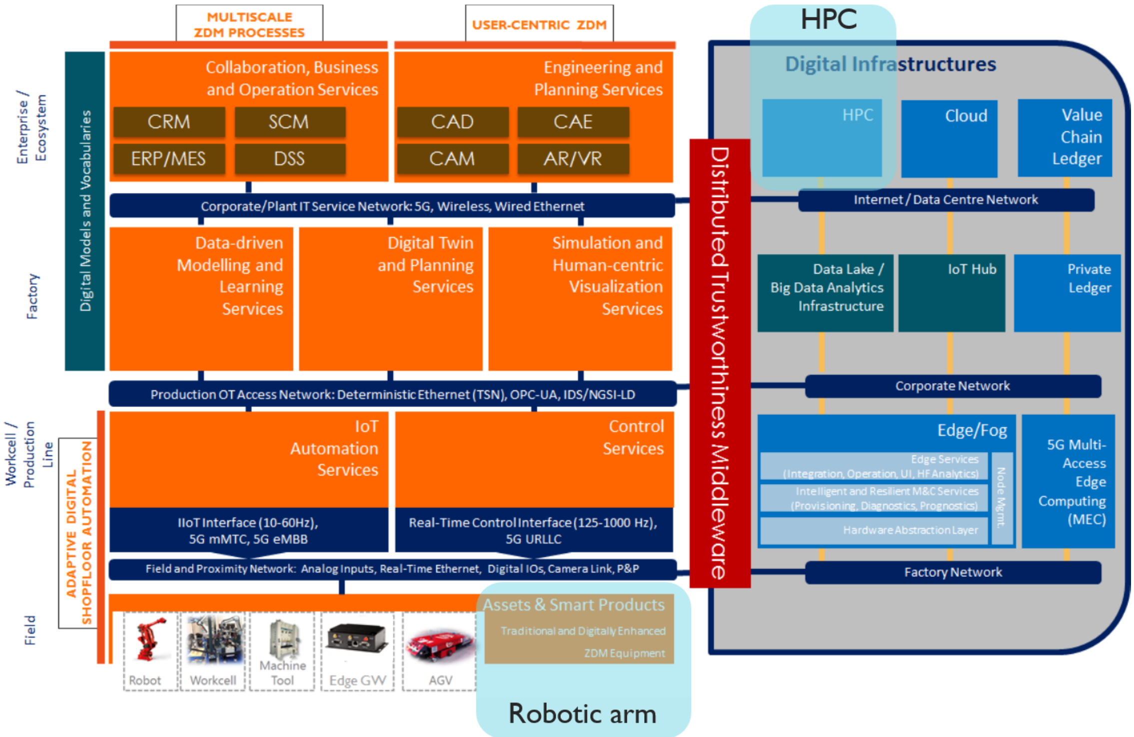

Figure 23: JSI equipment used according to the Qu4lity RA

According to the reference architecture (see Figure 23), the evolution of the robotic arm (WP4) and ReconCell software (WP5) are closely linked to the assets and smart products layer. In the Kolektor pilot, the HPC infrastructure will be used for complex analytics pipeline and other data-driven processes modelling.

4. Conclusion

This deliverable concludes the task 6.1 of WP6. A certain number of Technical Experimental Facilities have joined the Qu4lity project initiatives and share the same ambition of sharing technology enablers, specialized or enhanced equipment and processes to enhance production quality and reduce defects.

Across Europe, eight TEFs exchange their views and know-how to host experimentations that demonstrate how AI, digital infrastructures, new technologies can be employed in a brownfield fashion:

- The ASF facility address a use case of remote virtualization of production environment using 5G technology developed in the Qu4lity project.
- The FFLOR facility will integrate IEEE TSN technology to enable use of standard IEEE Ethernet technology to achieve deterministic communications in presence of best effort and critical traffics on the same medium.
- The JSI facility has setup a new functionality for adaptive visual quality inspection using robotic arms, camera, and complex algorithms for trajectory estimation. This functionality can be used to detect defects as soon as possible in the production chain.
- The I4.0 facility has extended its infrastructure to support multiple means of interacting with the processes (such as Augmented Reality), new sensors to obtain more information on vibrations and sounds, and new components to interpret sensors data and predict the behavior of the system.

Even though the COVID-19 situation has slowed down development and deployment of enhancement in TEFs, there are still expectations to see more enhancement planned in the future and more experimentation to be hosted on the TEFs.

List of figures

List of Abbreviations

TEF	Technical Experimental Facility
AR	Augmented Reality
AGV	Automated guided vehicles
AI	Artificial Intelligence
ASF	Automotive Smart factory
CAD	Computer-Aided Design
CI	Continuous Integration
CPS	Cyber Physical System
DB	Database
DIH	Digital Innovative Hub
HMI	Human Machine Interface
HPC	High Performance Computing
MEC	Multi-Access edge Computing
MES	Manufacturing Execution System
PLC	Programmable Logic Controller
PnP	Plug and Produce
Qu4lity RA	Qu4lity Reference Architecture
TSN	IEEE Time Sensitive Network
VR	Virtual reality
ZDM	Zero Defect Manufacturing

Partners: