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QU4LITY

DIGITAL MANUFACTURING PLATFORMS FOR CONNECTED SMART FACTORIES

D5.2 Framework for User-Centric ZDM Processes (Final Version)

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Abstract: This document presents the key concepts and considerations about human-in-the-loop ZDM processes on which Task 5.1 focuses. The knowledge base that has been set up during the progress of the activities is described.

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Contents

HISTORY

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1. Executive summary

The current deliverable aims to report about the results achieved by task *T5.1 - User-Centric ZDM, Distributed Process Co-Engineering and Augmented Reality*, as well as to provide the key concepts and technologies on which the task operated.

The purpose of T5.1 is to provide a framework to support the specification and the integration of autonomous ZDM processes that entail humans in the loop. This document presents the result of such an effort.

To provide a proof-of-concept of the proposed framework, this document presents a list of technologies and tools developed by the QU4LITY project, which enable the implementation of ZDM processes entailing humans in the loop. Their presentation was mapped against the developed template, with the twofold objective to validate the framework against practical cases and to support further development of ZDM technologies entailing human-in-the-loop.

Overall, this report clarifies the concept of human-in-the-loop ZDM processes and proposes a classification for the different types of ZDM processes entailing humans in the loop. Such an approach to classify those processes is based on the type of information flow that is involved in the interaction between the human operator and the tools/technologies adopted to achieve the desired quality performance for the product/production process of interest.

2. Introduction

The purpose of T5.1 is to provide a framework to support the specification and integration of autonomous ZDM processes that entail humans in the loop. These include distributed co-engineering processes and augmented reality processes, including processes for remote maintenance and training in ZDM-related tasks.

The task activities started focusing on identifying the key elements that play a role in the implementation of human-in-the-loop ZDM processes and worked on proposing a structured vision about the different categories of interactions in which human operators are involved while participating actively in ZDM processes.

Task T5.1 followed then a progressive iterative approach, refining step by step an organic vision of the several aspects involved by the entailing of humans in the loop, both from the technological and functional perspective.

Deliverable D5.1 provided an initial theoretical classification, which was progressively matched with a number of actual implementations, in order to verify in practice its applicability as a concrete framework, useful to leverage the technologies provided by the project partners.

The approach to identifying requirements and design patterns, associated with the development of application frameworks focusing on human centric ZDM processes, was then to analyse the specific key aspects and key technologies involved in the implementation of autonomous ZDM processes, especially focusing on their divergence and novelty on respect of the standard human-machine interactions.

The actual experiences from the pilots were observed and analysed, in order to consolidate them against the developed framework.

This final report, therefore, reviews and reorganizes the concepts and key elements previously identified, organizing them in form of a framework, which could support the development of technologies enabling human-in-the-loop AQ processes.

The overall structure of this document is as follows:

- Section 2 introduces the overall document.
- Section 3 presents the relations between T5.1 and other tasks of WP5, as well as with the overall QU4LITY vision.
- Section 4 focuses on the concept of human centric ZDM process.
- Section 5 define and describe the proposed framework, detailing the main concepts on which it has been conceived and formulated.
- Section 6 provides a list of technologies brought into QU4LITY by the partners of the Consortium, mapped to the developed framework.
- Section 7 concludes this document with a few considerations.

3. How T5.1 fits in the QU4LITY Vision for AQ

Task 5.1, as part of WP5, contributes to the overall goal of enabling and fostering the implementation of Autonomous Quality, providing the means that support and improve the engineering, deploying and management of ZDM processes.

Task 5.1 focuses on the ZDM processes where the presence and role of humans is a key aspect for the achievement of the objective established at product and/or production level, in particular in terms of quality performances.

Even though QU4LITY addresses the development of innovative and autonomous ZDM processes where the "Autonomous" attribute is strongly characterized by the exploitation of more and more performant Artificial Intelligent technologies and autonomic Cyber Physical Systems (CPS) capable to respond rapidly and effectively to the production requirements associated to ZDM, humans remain an essential part of the manufacturing processes.

As described in the project's vision, QU4LITY focuses on the development of ZDM processes that can be characterized with a degree of autonomy corresponding to "Production Level 4". Those are systems that can perform their functions autonomously and adaptively within a well-defined set of boundaries. This notwithstanding, human beings keep the supervision responsibility, at least for the most relevant aspects, and they can intervene in emergency situations.

User-centric perspective remains an essential aspect of the autonomous ZDM processes: it needs to be addressed adequately in order to provide the means that support the engineering of manufacturing processes which aim for AQ.

QU4LITY aims to address and support the implementation and management of ZDM processes in a proper way. This is also demonstrated by the attention that QU4LITY pays on the "human factor" in the definition of its Reference Architecture, identifying a specific functional domain to the User-Centric ZDM [1]:

User-Centric ZDM*: This domain maps all the services where a human (or even an external system) can interact with the QU4LITY solutions, play any number of roles in a ZDM system — who may conceptualize, design, build and operate ZDM processes.*

At the same time, the QU4LITY Reference Architecture considers the relevance of humans being role in the AQ processes also from the Service Domains perspective [1]:

Human Domain*: The Human domain accomplish with end-user needs, providing use-to-use and user-friendly interfaces, and supporting the development and access to ZDM Applications built on top of information and services managed by the overall framework. Existing design and engineering tools, as well decision-supporting applications may fit in the scope of this domain.*

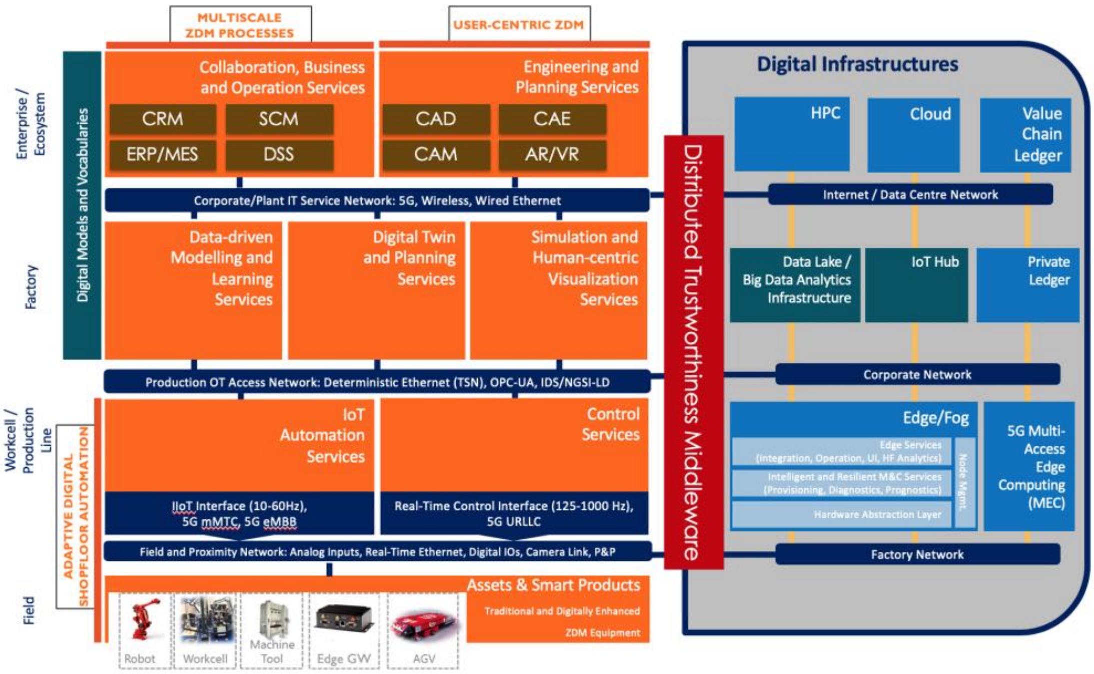

Figure 1 QU4LITY Reference Architecture

T5.1 activities are part of the overall work plan put in place by WP5 to enable ZDM processes based on AQ paradigm. The synergies with the other tasks of WP5 can be briefly described as follows:

- **T5.2** focuses mainly on the customization and integration of simulation processes and digital twins on the multi-stage ZDM processes based on AQ. Simulation tools and the associated digital twinning technologies are commonly exploited in human centric ZDM processes where the skill of human operators is leveraged to impact positively on the final quality of products and production processes. Therefore, simulation platforms are a common topic for T5.1 and T5.2, although T5.1 perspective is mainly focused on the interaction with users.
- **T5.3** addresses the capability of digital platforms' operations of being adaptive to changing conditions of the shop floor. Synergies between T5.1 and T5.3 are mostly related to the HMI and interaction mechanisms that the workers can have at shop floor to contribute to the keep high quality production levels in continuous evolving work conditions and in collaboration with self-adapting automated systems.
- **T5.4** is a task that focuses on the interoperability of the digital platforms exploitable for the implementation of ZDM processes and on the Open APIs that can be exploited for that purpose. Since digital platforms and tools are also enablers for the implementation of human-in-the-loop ZDM processes, T5.1 and T5.4 will share some common synergies in terms of Open APIs most relevant for those processes.

- **T5.5** addresses the enabling of autonomous data management operations by integration of the digital platforms to the open secure Industrial Data Space. At this stage of T5.1 activities, synergies between T5.1 and T5.5 are not clear yet. It looks probable that the adoption of a distributed and shared Industrial Data Space has some impact on the collaborative ZDM processes that entail humans in the loop, but concrete scenarios and examples have not been identified so far.
- **T5.6** focuses on the integration of functionalities from multiple platforms to enable an open and integrated service engineering approach. Considering that some services could involve the interaction with human operators in the implementation of ZDM processes, they might be the common point of collaboration between T5.1 and T5.6.

4. Human-in-the-loop AQ processes

The AQ paradigm for ZDM in connected smart Factory 4.0 aims at reducing the human input in the data analysis and process control to achieve the automation of the loops of information through improved use of more complex control systems, as described in D2.3. Nevertheless, the main goal for a ZDM process is to achieve autonomous decision-making processes that assure the quality of production processes and related output. This can be achieved by leveraging self-governing mechanisms as much as possible but the presence and participation of humans in the smart Factory 4.0 remains essential.

Despite human operators provide an invaluable level of flexibility in learning and executing new tasks, the effort needed to teach frequently new operative procedures is expensive and the constancy of production quality levels is not always guaranteed. Additionally, such a scenario may cause negative impacts on the workers well-being and job quality, especially when the operations are repetitive, need to be performed fast and the environment is harsh.

The methodological change required to face the ever-increasing needs of production flexibility is also combined with a shift of the role of the workers that can be assisted or replaced by the robotic handling systems in tasks for manipulation of flexible materials and that have to be trained both for collaborating with the robots and to perform the configuration of the robotic cells by means of appropriate software tools, like those developed in this project.

The workplaces of the future are expected to be worker-centric (as opposed to task-centric), with an increased role of workers in pursuing production performances and personal well-being. In this new paradigm, it is the task that suits skills, experience, capacities and needs of the worker, here turned from a passive constraint to a variable opportunity.

Advanced algorithms and tools based on artificial intelligence are expected to augment the mutual perception and understanding of the behaviour of the automated systems (robots, machine tools) and operators, for an effective approach in executing joint tasks and resulting in better quality performances.

The model that QU4LITY proposes to achieve AQ in ZDM processes takes in consideration the participation of persons in the processes of the FACTORY 4.0 and T5.1 aims to provide the means to support the specification and integration of autonomous ZDM processes that entail human in the loop.

The human knowledge and experience play an essential role in many tasks of a manufacturing process, both at the shop floor level and at the engineering and management level.

The reduction of scraps and the improvement of product and process quality can be achieved through the adoption of the new and enabling technologies that, exploiting artificial intelligence (AI) algorithms and machine learning (ML) tools, make more automatic the closing of control loops that affect the functioning of the production systems. However, humans remain a key asset for a ZDM process, that intervene in many phases and tasks of the production chain and in different steps of a product life cycle.

Thanks to the enhanced capability to collect data from many sources and the possibility to process the enormous quantity of rough data by means of advanced algorithms capable to extract and provide to human's information about the current status of the production quality and suggestions for the actions that could be taken, the persons play a primary role in the actuation of control mechanisms where they are taking an integrated part in the loop of the action:

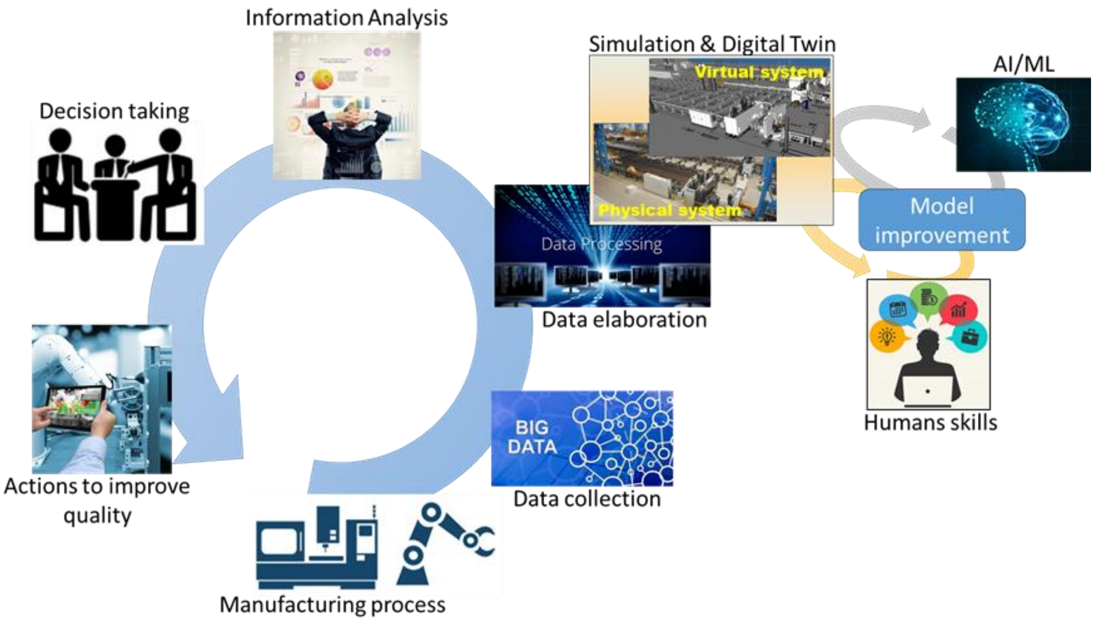

Figure 2 Control loop where the human operator is part of the control action

In the context of the autonomous ZDM processes, therefore, humans are "in the loop" of many processes that require to take decisions and control actions to achieve the desired quality performance objectives and contributing to the AQ paradigm.

Human operators play a relevant role in taking decisions and actions that contribute to the achievement of the product/production quality at different stages of a ZDM process' life-cycle. The human skills are exploited at planning phase, for design and engineering of product and/or processes that are expected to satisfy appropriate KPIs, including quality parameters. The definition and planning of quality measures is for instance a task where human contribution is essential. During the operation phase, while the manufacturing process is operative, human experience and know-how is leveraged to intervene in all those situations where the autonomous mechanisms for ZDM need the supervision by a human operator and also for tasks where the person cannot be replaced by automated systems (for instance in maintenance activities). Also, at the performance analysis phase, when the product and/or production system is evaluated to check that the quality objectives are satisfied, human operators complement the automatic quality check technologies adopted to enhance the overall quality performance and contribution, to manage appropriately situations where those automatic mechanism have some limits.

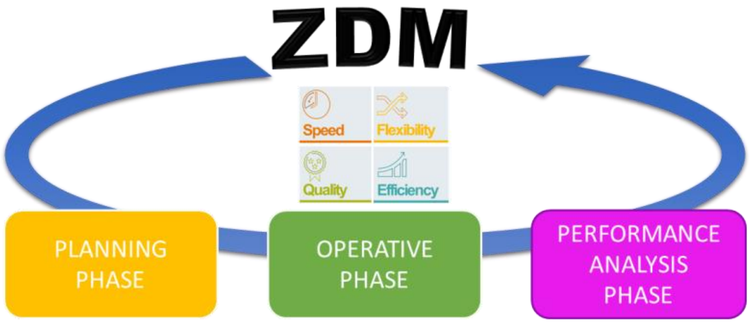

Figure 3 Different phases envisioned in some multi-stage ZDM process.

5. A framework for human in-the-loop in ZDM

To derive adequate understanding and awareness about how the human being is integrated in ZDM processes and what are the relevant elements that T5.1 has to consider for the development of a Framework supporting user-centric ZDM processes, the activities of T5.1 focused on identifying and structuring the different ZDM processes that involve the human operator as a key element of the process.

Such analysis has been performed considering the information available from the official documentation produced in the QU4LITY project as well as the know-how provided by the project partners, which actively contributed to T5.1.

The data gathering was mainly addressed within the partners contributing to T5.1 by circulating a questionnaire. However, also other information available from the project documentation and direct interactions was included, where possible. The template shared with the partners wanted to support the collection of information regarding the several **H**uman-**I**n-**T**h**E**-**L**oop **Z**DM processes ("HITELZ" processes) that can be identified in the ZDM manufacturing context.

Specific information about each of the technologies, provided by the project partner proposing the solution, have been collected following a structured template, where details have been reported for each of the proposed categories.

Eventually, in the next section, an overall summary will be presented, where all the analysed technologies have been mapped on the reference framework and described in detail, which are specific of each of those qualified characteristics.

The table extract, hereafter, anticipates the overall summary of the tool collection and analysis, which will be presented in section 6.

		Categories of human in-the-loop processes in ZDM					Tools and technologies for user centric ZDM processes						ZDM process phases entailing humans in the loop			
Technology name	Pilot	Supervision	Investigation	Prescriptive guidance	Predictive support	Collaborative	AR/VR/MR/ XR tools	Simulation tools	Engineering/ design tools	Information presentation tools	Methodologies	Collaboration/co-engineering	R&D/Design/ engineering	Procurement/Plant	Manufacturing	Service
Technology 1	Pilot1															
…	…															

Each of the mentioned categories are discussed in the following of the present section, highlighting the aspects specifically relevant for AQ.

Processes	Categories of human in-the-loop processes in ZDM
Tool category	Tools and technologies for user centric ZDM processes
Phase	ZDM process phases entailing humans in the loop

Categories of human in-the-loop processes in ZDM

The legacy manufacturing processes and the improvement of quality performances were supported mainly by tools that generate descriptive information about the current status of a specific system, leaving to human operator the complete responsibility to discover, understand, estimate and take decisions. The new generation of autonomous ZDM processes, which development is actively pursuing in the QU4LITY project, leverages a full range of technologies that support the human work providing **different levels of awareness**, which surpass the standard processes of human-machine interaction.

- First level: **descriptive** – the tool provides a mean for the human to analyse what is happening on a specific system.
- Second level: **diagnostic** – the tool supports the human to understand the reasons of some specific system behaviour.
- Fourth level: **prescriptive** – the tool provides indications and/or guidelines to the human operator about the actions that should be accomplished to achieve a desired status for a system.
- Third level: **predictive** – the tool leverages data sets and other technologies (AI/ML algorithms, digital models …) to estimate a possible future behaviour of a system.
- Fifth level: **collaborative** – the tool allows cooperation between several humans, so leveraging the readiness, the experience and the knowledge of each of them.

Figure 4 Categories of human centric ZDM processes.

Actually, the fifth level could be considered as a horizontal dimension, as it could actively contribute to the full expression of all the previous levels.

A set of categories for ZDM processes that entail human in the loop could therefore be identified. The approach here, adopted to identify them, is based on the type of information that the human operator receive as input from the external tools and the type of action performed by the person.

Specific information about each of the processes, as provided by the project partner proposing their solutions, have been collected by the following template, which was circulated as a questionnaire during the task development.

Processes	Supervision	...
	Investigation	...
	Prescriptive guidance	...
	Predictive support	...
	Collaborative	...

Supervision processes

This category of ZDM processes includes all those processes where the human operator can monitor the status of a system or a product (finished or semi-finished) leveraging some kind of tool, which provides the required information to the operator. Normally the supervision process does not require the person to take specific actions in addition to what is needed to perform the monitoring appropriately. Only when particular situations arise the operator is warned about the anomaly and leveraging his skills and know-how, he decides the actions to take, in order to reduce the impact on the quality KPIs of the product/production process.

Human centric ZDM supervision processes can be identified at all the three higher layers in which the digital services of the QU4LITY model are structured (Work Cell/Production Line, Factory, Enterprise) and many different digital technologies can be used to interact with the human operator. Mostly these human-in-the-loop processes are based on the exploitation of visualization tools and interfaces that enable the person to receive the information needed for the supervision task. But, in general, also other kind of technologies that use other types of interaction can be envisioned (like sound making tools and wearables that vibrate). Common tools adopted for this purpose are HMI and SCADA at Work Cell/Production Line level, SCADA and MES at Factory level. Also, AR and MR technologies can be adopted to provide all the information a human operator needs to supervise and intervene when needed on a machine tool and/or a production line.

Investigation processes

ZDM processes in this category are those processes where human operator is supported by means of some kind of tool in the analysis of specific system behaviour or product quality test results, and the human operator is allowed to access in a fast and effective manner to all the information available and useful for the human to take some kind of decision that affect the quality performance of the product/production process.

Human centric ZDM investigation processes are commonly located at Factory level, where the management (from both technical and business areas) exploit digital technologies to analyse the behaviour and performance of a product/production process leveraging the data and information that the digital tool make easily accessible. The investigation processes are not limited to the analysis of results associated to products and processes already in production, but they also include the designing and engineering tasks which leverage the digital technologies to develop new products/production processes.

ZDM investigation processes can entail human operator also in some tasks at Work Cell/Production Line level. To achieve the desired quality goals, certain ZDM processes require the intervention of a skilled human operator to evaluate the elaborations and information provided by a digital tool (usually an interactive visualization tool) and then take decisions about how to proceed with the production. An example of this processes can be the check and optimization task performed by the human operator who analyse the result of a CAM simulation before the machining of the workpiece starts, or the evaluations that the skilled operator of an Additive Manufacturing (AM) machine tool does when leverages a visualization tool reporting the details of the deposition process to decide how to intervene for optimization of the quality performances in the following machining jobs.

Generally, the digital technologies adopted in this category of ZDM processes enable the person to interact with the tool in order to investigate and analyse the data. Interactive visualization tools are the most common but also the simulation tools play a relevant role. By means of iterative simulations the human operator can achieve better understanding of the data under analysis and can use them to identify the best scenarios. As result of the investigation the human operator can take the appropriate decisions on the product/production process and affecting quality KPIs. AR tools are also very suited for implementing this category of human centric ZDM processes.

In this category of human centric ZDM processes the information flow is characterized by a set of interactions that goes from the human being to the digital tool, before the human takes a decision/action: basically, the person communicates to the tool the set of information and aspects that are more relevant for the specific task under consideration. For instance zooming a certain area of a 3D model, selecting a menu which then triggers the visualization of further data, etc..

Prescriptive guidance processes

This category includes all the ZDM processes where the human is entailed in the information flow and where the human receives guidance for the actions that can and/or should be done. The human-in-the-loop processes of this category leverage the skills of the person while reducing the risk of wrong actions. The operator is removed of some responsibilities in taking decisions and, therefore, can work in a less stressful context reducing at the same time the eventuality of errors.

Human centric ZDM processes of this category are generally implemented to speed up tasks that could be delayed and or affected by wrong or sub-optimal decisions of the human operator, in particular when they need to be performed in anomalous/stressful conditions (for instance when a system in the production line is malfunctioning). These kind of human-in-the-loop ZDM processes are therefore commonly implemented at Workcell/Production Line level, where the operator is guided in the actions to take by means of some digital technology. Visualization tools integrated in the HMI and SCADA applications leverage the graphic panel normally used for supervisory tasks. AR and MR are another example of technologies suitable for that purpose.

Prescriptive guidance processes include also those human-in-the-loop ZDM processes where the person is guided to do a specific task. Considering the highly automated ZDM production systems addressed by QU4LITY the tasks where the human dexterity is exploited for the manufacturing process is reduced to the minimum. Nevertheless, human workers are still essential in some manufacturing sector and digital technologies that enable to guide the actions of the persons are also relevant. This means that AR/MR tools, but also sound making tools and vibratory wearables, can be exploited in different scenarios: to instruct the operator during a maintenance task on a system; to move effectively in a complex plant, respecting safety path and precedence with AGVs; to collaborate effectively with robots.

For instance, by means of AR-based glasses the operator can be helped in their production task. By adopting this kind of technology for human centric ZDM processes, Boing cut production time by 25% and lowered error rates to nearly 0 [1], and other companies allowed new operators to get Standard Operating Procedures right the first time, and 25% time saving for existing operators [2].

Training activities that leverage the digital technologies, like for instance AR/MR, to provide guidance in order to perform certain tasks accurately and in order to guarantee prescribed quality, performance levels are also included in the category of human centric ZDM processes. The transformation from the paper-based documentation to AR-based increases the efficiency of quality assurance processes and training [3].

Predictive support processes

ZDM processes in this category leverage some kind of digital technology to provide the human operator with information that help to estimate the behaviour/properties of a product or system currently under design/evaluation.

Here the skills of the human operator are exploited to set up the most appropriate conditions from which the tool elaborates a prediction, which quality depends on the starting conditions of the computations. The operator has then to take decisions about how to continue with the analysis of results, possibly repeating many times the elaboration while tuning the starting conditions, and when to stop the analysis and take conclusions/actions.

The human centric ZDM processes of this category include all those processes that entail the human to analyse the results generated by simulation tools that aims to predict the future KPIs associated to products and or production processes. These processes can therefore be exploited along all the three phases that characterize a ZDM process: planning, operation and analysis of the performance.

Simulation platforms are therefore the most relevant digital technology associated to this category of human-in-the-loop ZDM process, together with the digital twinning technologies that enables to make more accurate and reliable predictions. These technologies are largely exploited in this category of human-in-the-loop ZDM processes to optimize and improve the quality KPIs of systems and/or products.

Collaborative processes

This category includes all the ZDM processes that entail more than one human in the flow of information and decision making, and where the information does not flow in just one direction, from the tool to the operators, but operators can alter and enhance the information available through the tool and make it available to the other collaborators. In this category of processes, the most relevant aspect is the possibility for many persons to collaborate in the analysis of information and/or in the decisions making that then results in actions that affect the quality KPIs of products and or production process.

Co-engineering tools are a technology enabler for this category of human centric ZDM processes, providing the means for teams to collaborate in common design and development projects.

Other examples of digital technologies that can be exploited in the implementation of human-in-the-loop ZDM collaborative processes are the broad class of collaborative tools, which enable teams to work and collaborate remotely, also for decision making and planning activities that have direct impact on the production, and technologies that support the remote training.

Actually, as just mentioned in the introduction, the collaborative dimension could be considered as orthogonal to any other type of processes, as it provides the potential to enhance all of them, from the simpler supervision to the more challenging prediction ability.

Tools and technologies for user centric ZDM processes

This section is dedicated to the description of digital technologies and tools that can be leveraged for the implementation of ZDM processes that entail humans in the loop.

The technologies and tools that can be considered enablers for the implementation of HITELZ processes can be distributed in five groups:

- AR/VR/MR/XR technologies
- Simulation technologies
- Engineering/Design tools
- Information presentation tools
- Methodologies
- Collaboration/Co-Engineering tools

Again, similar to the human-in-the-loop processes, the category of Collaboration/Co-Engineering tools could be interpreted as horizontal on respect of the others, as it offers the potential to share experiences, knowledge and actions over different activities.

Specific information about each of the technologies, as provided by the project partners proposing their solution, have been collected by means the following template, which was circulated as a questionnaire during the task development.

Tool category	AR/VR/MR/XR tools	...
	Simulation tools	...
	Engineering/design tools	...
	Information presentation tools	...
	Methodologies	...
	Collaboration/co-engineering	...

AR/VR/MR/XR tools

The objective of VR is to allow the user to virtually execute a task while believing that they are executing it in the real world. To generate this sensation, the technology must “deceive the brain” by providing it with information identical to the information the brain would perceive in the real environment. Commonly the VR technologies exploits some kind of headset which provides the visual information to the person and offer a good immersion experience as the only visual information perceived is delivered through that device. Most recent VR technologies use devices that are at the same time video and audio headset, providing a greater immersion perception. To interact with the virtual environment, the VR technologies leverages systems of different type (joysticks, drive wheels, Kinect, etc.). The interaction mechanism between the user and the system is the second fundamental principle of VR. It also serves to differentiate VR from applications that offer good immersion but no real interaction.

The goal of AR is to enrich the perception and knowledge of a real environment by adding digital information relating to this environment. This information is most often visual, sometimes auditory and is rarely haptic. In most AR applications, the user visualizes synthetic images through glasses, headsets, video projectors or even through mobile phones/tablets. The distinction between these devices is based on the superimposition of information onto natural vision that the first three types of devices offer, while the fourth only offers remote viewing.

MR technologies consist of blending virtual objects and seamlessly into the real world in a way that appears natural. Therefore, MR technologies exploit devices which enables to visualize different video sources in a mixed way (video headsets, tablets, etc.)

Extended reality (XR) is a term referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables, where the 'X' represents a variable for any current or future spatial computing technologies.

Technologies in this group are mainly exploited to implement ZDM processes that entail the human operator in the loop when the task addressed need the user to be “immersed” in an enhanced reality to be accomplished effectively. Human centric ZDM processes of these kind are, for instance, remote training, remote support services and prescriptive guidance processes.

Simulation tools

Simulation tools are key technologies in the implementation of ZDM processes. Although state of the art simulation platforms enable to leverage the simulation tools within automatic mechanisms of elaboration and optimization addressing specific design tasks, the simulation technology is largely adopted in user centric ZDM processes, where the skills of the human operator are exploited to achieve satisfactory quality performance levels.

Human-in-the-loop ZDM processes leverage the simulation tool to evaluate the behaviour of a system/product. The flow of the information in which the human operator is involved is therefore bi-directional and iterative:

1. **Starting from a configuration** of the initial conditions and elaboration parameters (defined by the user).
2. The simulation elaborates the data and **generates the results**.
3. If the analysis is not completed, the user modifies the boundary conditions of the simulation, possibly supported by the tool, and **iterate the simulations**.
4. The user confirm the results: his **decision** directly affects the quality of the resulting product/process.

Human centric ZDM processes that use the simulation tools to achieve the desired goals in terms of quality can be identified at different phases of a ZDM process life-cycle:

- *At planning phase*: simulation tools are exploited to forecast the quality performance of the production process/product and to make what-if analysis.

- *At performance analysis phase*: simulation tools are exploited to investigate on the production issues that affect the production process/product quality, and support on the tuning and optimization of the quality KPIs.

Simulation platforms leverage some kind of underneath modelling technology to elaborate and generate their results. In this context Digital twining technologies are strictly related to the simulation tools and enable to have a more realistic synchronization between the real world, where the automated production processes take place, and the virtual one, where models of machines and products are improved by the exploiting of the digitalization of the processes and the large amount of monitoring data collected from the shop floor.

Design tools

AI capabilities are improving rapidly and functionalities that support in the design task offering automatically generated solutions will be more and more available to the user of the engineering tools in the coming future. However, almost all the designing tasks we can encounter in autonomous ZDM processes entail humans in the loop. The design task is a human centric process where the knowledge, experience, and other skills of humans (like imagination, creativity, artistic abilities, etc.) are exploited to achieve the desired KPIs, also in terms of expected/achievable quality performances.

Designing tools are only used at the planning phase of a ZDM process life-cycle, because of their nature: these tools are exploited to design new products and/or production processes associated to desired quality objectives.

Information presentation tools

Many different technologies can be included in this category. The main purpose of those technologies is to provide information to the human operator via some kind of device. The **visualization tools** are the most widely exploited since they can generally show graphic representation of data and therefore result very effective in the goal of delivering the information to the user. Visualization tools make use of different kind of devices to present the information to the user: screens, headsets, tablets, mobile phones, wearable devices, but also simpler solutions like semaphores, light panels, etc.

In human centric ZDM processes where it is important to assure high quality production levels, having human operators completely aware of the context in which they are working is essential. That awareness is not always restricted to the specific tasks that the operator has to do but can also consider other aspects, like for instance:

- the current status of systems that he has to supervise, but not necessarily always nearby
- having some understanding about the imminent behaviour of the automated systems with which he cooperates (like AGVs and collaborative robots)

In this wider scenario of information that the human operator could leverage to work and guarantee the established quality performance, also other digital tools can enable the implementation of human-in-the-loop ZDM processes.

Technologies that exploit **sound making devices** and **wearable vibratory devices** are for instance other kind of tools that can be leveraged to inform or provide guidelines to the operators.

The technologies of this category are mostly focused on providing information to the user, therefore the flow of information is mainly forming the digital tool to the user. Nevertheless, these tools often provide the possibility to interact with the tool, enabling the operator to investigate and recover the data that is more relevant for the understanding of specific aspects of interest.

Methodologies

Among the tools that enable the implementation of human centric ZDM processes, we can also include the category of methodologies dedicated to the design of ZDM processes entailing humans in the loop.

This family of tools is quite variegating and is composed, for instance, by digital tools, by paper based methodologies and by best practices.

In general, these tools support the management of production processes addressing in specific way the human factor in ZDM process

Collaboration/Co-Engineering tools

One particular family of tools that are enablers for human centric ZDM processes is composed by collaboration and co-engineering tools.

The main characteristic of these technologies is that they enable a team of persons to collaborate remotely to accomplish a certain task that has impact on the quality KPIs of the product/production process. The human operator is involved in many bi-directional flows of information, with both the tool and the other participants.

The overall interactions that each user has with the tool generate the final outcome of the collaboration and therefore the decision/actions which, in turn, impact on the quality aspects of process.

Collaboration tools are exploited to implement different type of human centric ZDM processes:

- To implement remote support services.
- To implement remote training services.
- To implement collaborative designing projects.
- To share awareness in supervision tasks.

ZDM production phases entailing humans in the loop

This section presents a classification of the human-in-the-loop processes which is based on the different phases of the production activity.

Based on the observation and the experience gathered from the involved partners, this phases have been identified, which will be better described in the following:

- R&D/Design/ engineering
- Procurement/Plant implementation
- Manufacturing
- Service

Here, the framework proposes a specialization of the Planning phase in Design/Engineering and Plant implementation, focusing on their specific characteristics. This is due to the different aspects that the subject of the planning activity implies, whether it is the final product or the production environment that enables its manufacturing. Such a distinction also impacts on the requirements and solutions related to the involvement of human operators in the corresponding process.

The Performance Analysis phase also presents similar specializations, whether it is referred to the production process or to the involved technologies. Therefore, the framework maps them to Manufacturing or Service, depending on the subject.

Specific information referred to each of these phases, which has been provided by the project partners describing their tools, have been collected by means of the following template, which was circulated as a questionnaire during the task development.

Phase	R&D/Design/ engineering	...
	Procurement/Plant implementation	...
	Manufacturing	...
	Service	...

In order to make the knowledge base for T5.1 as more general as possible and not limited to the specific QU4LITY use cases demonstrated in the pilots, the template circulated between partners asked also to identify HITELZ processes that are not directly related to the digital technologies in which each partner is expert and try to spot HITELZ processes addressable by means of other digital technologies, without need to refer to specific demo pilots of the project.

R&D/Design/Engineering

- ***Product planning***

Short description	The user must plan a product or production process to ensure quality of product and producibility, taking available production skills into account.
Type of interaction between human<->tool/equipment	Planning and simulation tools like CAD, CAE, CAM support the user in product design and design for manufacturing. Functional requirements of the product must be considered as well as available machining resource skills. Additionally, quality requirements like machining accuracy or strength must be considered in this design and engineering phase. User must interact with the tool by defining product geometry, material, component assembly etc. as well as electric, magnetic, thermal, and mechanical design assessment. Optimization methodology will support in decision.
Information flow direction	Starting with green field planning or loading available input data depending on tool import functionality for model generation (User->Tool). Assessment feedback from tool to user for interpretation and decision support (Tool->User). Iterative process.
Relevance for AQ	The better the planning beforehand the better the quality afterwards.
Tool/technology involved	Product and production design tools

Procurement/Plant implementation

- ***Production planning***

Short description	The user must plan the production process from machine level up to scheduling to ensure quality of production process beside time and cost.

Type of interaction between human<->tool/equipment	Planning and simulation tools like ERP or CAM support the user in production process design. Functional requirements of the product to be produced must be considered as well as resource skills and availability. Additionally, quality requirements and manufacturing in time, must take manufacturing machine wear and machining cost into account. User must interact with the tool by defining machining process configuration as well as production scheduling and evaluate different options and uncertainties. Optimization methodology will support in decision.
Information flow direction	Starting with green field planning or loading available input data depending on tool import functionality for model generation (User->Tool). Assessment feedback from tool to user for interpretation and decision support (Tool->User). Iterative process.
Relevance for AQ	The better the planning beforehand the better the quality afterwards.
Tool/technology involved	Computer Added Manufacturing tools for machining process configuration as well as material flow and scheduling tools for resource planning.

Manufacturing

- ***Production management***

Short description	The user must control the production process quality by quality key performance indicators (KPI) to track the targeted quality.
Type of interaction between human<->tool/equipment	A management dashboard visualizes the aggregated current KPI values compared to KPI target values. In case of underperformance the user needs to dive deeper and select the appropriate production subsystem or machine and to diagnose the problem or malfunction. Therefore, historical process data must be available and visualized as well as trend prognosis. Analysis and prognosis functionality as background functionality is necessary, like data-based analysis models or predictive maintenance models.
Information flow direction	The management tool provides information to the user (tool -> user). The human operator interacts with the tool to manage the production (user -> tool).
Relevance for AQ	Information aggregation for management control and user guidance for analysis and decision making.
Tool/technology involved	Condition based monitoring and control, diagnosis and predictive maintenance tools and models.

- ***Workcell/Production Line supervision***

Short description	The human operator can monitor a set of information relevant for his work and is warned whenever anomalies arise
Type of interaction between human<->tool/equipment	The human looks at some visualization device: graphics panel, video terminal, lights on a dashboard. The human listen to specific alarms/sounds/speech messages. The human feels that a wearable device vibrates in a well-defined pattern.
Information flow direction	Digital tools -> Human -> Digital tools
Relevance for AQ	The human operator can be aware of the current status of the system and can intervene through appropriate actions if it considers right to do so. Therefore, the operator implements a human-in-the-loop control action, where the decision of the specific action is fully demanded to the human
Tool/technology involved	• Visualization tool • Sound making tool • Vibrating wearable device

- ***Operator support***

Short description	The user in the field must operate at machine or product and needs feedback regarding the machines or his work, if the machining process is good (pass) or not good (fail). In case of fail, repair or rework could be necessary.
Type of interaction between human<->tool/equipment	Quality measurement equipment (test equipment) is necessary to give the information about the product or machining quality. This measurement must be post processed to give interpretable information to the user about how good the quality is or what is the root cause for not good enough quality. As this quality control process is not adding value to the production value chain, it must be low time and cost consuming. Therefore, easy interpretation is necessary like traffic light (green, red) or sound, and in case of red, additional information to support in decision of further treatment.
Information flow direction	Test station -> operator
Relevance for AQ	The human operator can be aware of the current status of the system and can intervene through appropriate actions if it considers right to do so.

	Therefore, the operator implements a human-in-the-loop control action, where the decision of the specific action is fully demanded to the human.
Tool/technology involved	Test equipment, test result visualization like traffic light or monitor and/or sound

- ***Quality trend analysis and corrective actions***

Short description	Quality manager can analyse the quality trend of the current production by a Quality cockpit and take the corrective actions in presence of statistically significant deviations from the expected trend.
Type of interaction between human<->tool/equipment	Quality cockpit shows the quality trend and highlights any significant deviations listing possible corrective actions. Human operator decides which corrective actions should be taken based on the proposed list and the current values of different Quality KPIs (for instance calculated by the new quality system based on the MPFQ methodology).
Information flow direction	The tool for data visualization and analysis provides the results of the elaboration to the user (tool->user). The human operator interacts with the tool to investigate and achieve better understanding of the results (user->tool) and finally takes decisions on corrective actions.
Relevance for AQ	The quality manager is supported in the decisions making process by the Quality cockpit that shows possible corrections based on the actual quality trend of the production system.
Tool/technology involved	• Visualization tool • Data analytics tool to extrapolate information from data coming from the production system

- ***Support to management of quality check failures***

Short description	The human operator can monitor a set of information relevant for his work and gets additional information regarding product characteristics (e.g. failures)
Type of interaction between human<->tool/equipment	The human operator gets information due to a non-confirmed tested product. This can be done via an alarm or for example through a wearable device that vibrates. The human looks at some visualization device: graphics panel, video terminal, lights on a dashboard next to the production line.
Information flow direction	Digital tools → Human → Digital tools

Relevance for AQ	Failures need to be avoided in AQ processes. Here, especially pseudo error led to decreased production system performance. To identify those pseudo errors as fast as possible is vital to the process performance. Therefore, a human in the loop approach is followed. Through given quality and product related information, the human operator is supported in deciding whether the non-confirming part is an error or not.
Tool/technology involved	• Visualization tool • Sound making tool • Vibrating wearable device • API towards Model and Simulation tool • Connection to Data base/ MES

- ***Functional test calibration***

Short description	Production manager can calibrate the functional test on the final products
Type of interaction between human<->tool/equipment	Quality cockpit shows the quality trend of the current production. In presence of small deviations from the expected values, the production manager can calibrate the final functional test to check for quality conformity of the goods manufactured.
Information flow direction	The tool for data visualization and analysis provides the results of the elaboration to the user (tool->user). The human operator interacts with the tool to investigate and achieve better understanding of the results (user->tool) and takes decisions about test calibration.
Relevance for AQ	The production manager is supported in calibrating the final test to discover potential problems on the final product that could not be relieved using default testing procedure. Quality cockpit shows small deviation providing some hints on potential quality problems of the current production and suggesting a more specific functional test on the final product.
Tool/technology involved	• Visualization tool • Data analytics tool to extrapolate information from data coming from the production system

Service

- ***Maintenance scheduling***

Short description	The user must schedule maintenance tasks within the ordinary production scheduling.
Type of interaction between human<->tool/equipment	A tool could support in schedule planning of maintenance tasks (like ERP). If predictive maintenance is available also a range of maintenance tasks implementation will help in more flexible task integration into the ordinary production scheduling according to product order capacities.
Information flow direction	Scheduler tool -> interactive user.
Relevance for AQ	Quality management control and maintenance planning regarding zero defect manufacturing.
Tool/technology involved	Material flow and scheduling tools for resource planning

- ***Maintenance service***

Short description	In case of machine malfunction or product quality failure repair or rework must be done. The user must know the root cause for malfunction to know what the problem is and to react in the correct manner.
Type of interaction between human<->tool/equipment	A diagnosis tool shows the user the exact problem or probability of root causes and the options for repair. So, the user knows which expertise and which spare parts are necessary for machine repair or product rework. Also repair plan visualization could support in quick and successful repair work, like step-by-step AR or VR (remote maintenance).
Information flow direction	The digital tools provide information and guidelines to the user (tool->user). The human operator interacts with the tool to investigate and achieve better understanding of actions to be taken (user->tool) and implement the actions.
Relevance for AQ	Fast reaction in high quality to save time and cost.
Tool/technology involved	Diagnosis tool for root cause analysis and visualization for problem and resolve definition

6. QU4LITY's User-Centric technologies

The framework, applied

This section provides an overview of the tools identified as being relevant to exploit the competences expressed the QU4LITY project and to leverage the experience provided by their implementations in the QU4LITY pilots.

This overview is therefore supported by the backbone of the framework developed by task T5.1, with the twofold objective to validate it against practical cases and to support further development of ZDM technologies entailing human-in-the-loop.

The final selection of tools, presented hereafter, is the result of a progressive deepening in the understanding of their functionalities. It started from an initial review of the catalogue provided by T2.3 in the IoT-Catalogue portal [5], subsequently filtered by criteria of coherence and pertinence with the framework.

The following table offers a concise summary of the areas of functionality offered by each of the analysed and selected tools, which is then detailed in the individual description of each of them.

		Categories of human in-the-loop processes in ZDM					Tools and technologies for user centric ZDM processes						ZDM production phases entailing humans in the loop			
Technology name	Pilot	Supervision	Investigation	Prescriptive guidance	Predictive support	Collaborative	AR/VR/MR/ XR tools	Simulation tools	Engineering/ design tools	Information presentation tools	Methodologies	Collaboration/co-engineering	R&D/Design/ engineering	Procurement/Plant	Manufacturing	Service
Simulation Framework	SIEMENS															
Imaging System	RIA															
Kis DeepLearning	KOLEKTOR															
KiS Framework	KOLEKTOR															
Data Analysis tool	PRIMA															
Decision Support System	WHR															
Quality trend cockpit	WHR															
Pacelab WEAVR	Continental															
Design4AM	PRIMA															
Manual work support via AR (SpaceAR).	PRIMA															
Pseudo Error Reduction	SIEMENS															
Shopfloor visualisation	Continental															
IEC-61499 IDE and runtime	MONDR#1															
Additive manufacturing simulator	PRIMA															

Additional information

Beside the specific information aiming at qualifying the tools against the provided framework, additional information was provided by the partners, which are related to the development in the context of the QU4LITY project progress.

Such an information has been included in the tool descriptions by mean of a dedicated section, here shown as a reference

Test & validation	Pilot, WP	...
	Where	...
	Human Centric ZDM relevance	...
	Prototype plan	...
	Supported APIs	...

Selected collection of QU4LITY's tools and technologies

All the information provided in the following selection have been provided by the responsible partners, which contributed by answering to questionnaires circulated during the task development, providing project documentation, and participating to direct interactions.

Production and Process Simulation (SIEMENS)

Discrete Event, Multibody and physics Simulations are well established tools used for investigating production processes in detail, logistics of factories etc. during design phases, and are increasingly applied also for decision support during operation. While adaptations and enhancements are required per implementation case, the technology itself can overall be considered mature. Enhancements to simulation are expected for models of the product-process interactions and the outcome in terms of product quality per process and in the overall production chain. Furthermore, the interaction of the real and digital world shall be enhanced in order to use simulation as a tool for decision support during production execution. Depending on the decision situation this could require developing models which allow the simulation of the necessary results in limited time while keeping up a certain accuracy to be beneficial.

Simulation is used for investigating real-world behaviour in the virtual world, in general to investigate the outcome of e.g. organizational decisions or design alternatives before the actual implementation in the real world. Conventionally, this has been mainly applied during design phases, but recently receives an extension towards the implementation phase, what is considered as decision support.

In the Siemens Use Case, simulation is considered to investigate the outcome of possible adaptations – logistical decisions, parameter adjustments of processes – by simulation alternatives and valuing these based on KPIs. Based on those KPI-Ratings, alternatives are then to be selected in an automated or partially automated manner to be implemented in the production line considered in the demonstrator.

	Participant	SIEMENS
	Technology name	Multi-domain Simulation Framework
	Brief description	Framework to describe the workflow for production and quality assurance, with appropriate data model, services for

		simulation and assessment and aggregation of result in KPIs
Processes	Supervision	visualization of KPIs on a dashboard will support in decision on quality strategies
	Investigation	
	Prescriptive guidance	
	Predictive support	
	Collaborative	
Tool category	AR/VR/MR/XR tools	
	Simulation tools	The framework offers two options: Plant Simulation or Anylogic
	Engineering/design tools	
	Information presentation tools	Based on Web service
	Methodologies	Information exchange via common data model for different services
	Collaboration/co-engineering	
Phase	R&D/Design/ engineering	The tool could be exploited as a design tool for quality strategies to be applied in a production line.
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during the manufacturing of parts within the SIEMENS production line.
	Service	
Test & validation	Pilot, WP	SIEMENS, WP7
	Where	The PoC is based on a Plant Simulation model from Siemens Pilot with a production line. The results will also be validated by Siemens Pilot in Amberg.
	Human Centric ZDM relevance	The application is developed as framework and demonstrated for SIEMENS pilot.
	Prototype plan	
	Supported APIs	JSON

Imaging System (RIA)

The Imaging System offers a view of relevant information about the process, which could detect possible non-conformities in the product quality. The information is based on a database of standard defects, in order to evaluate them.

Based on the information shown on the integrated HMI, the operator could judge the process and decide to intervene whenever there is a detected non-conformity. The operator could therefore classify a piece as compliant or defective, possibly adding a new defect classification.

The tool also provides collaboration between the operator at the shopfloor and the data analysts in assessing the cause of quality degradation, in order to possibly retune the inspection system.

	Participant	RIA
	Technology name	Imaging System
	Brief description	The Imaging System will have an integrated HMI that will enable Human operator intervention whenever there is a detected non-conformity that is not in the standard defects database
Processes	**Supervision**	The operator can view on the HMI relevant information about the process and decide to intervene whenever there is a detected non-conformity
	Investigation	
	Prescriptive guidance	
	Predictive support	
	Collaborative	
Tool category	**AR/VR/MR/XR tools**	
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	
	Methodologies	
	Collaboration/co-engineering	The tool enables collaboration between the operator at the shopfloor and the data analysts in assessing the cause of quality degradation and tuning of the inspection system. The operator options will be: 1) No-defects: compliant piece 2) Defective: New defect classification
Phase	**R&D/Design/ engineering**	
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during manufacturing of parts.
	Service	
Test & validation	**Pilot, WP**	RIA, WP7
	Where	
	Human Centric ZDM relevance	The "imaging system" have an integrated HMI
	Prototype plan	
	Supported APIs	

Kolektor Digital Platform: Kis DeepLearning (KOL)

Kis DeepLearning is a tool to train deep learning models. It allows users to create, train, and analyse trained models in a user-friendly manner.

Datasets may be easily annotated, created, inspected and analysed by the operator, which can keep track of the current state and detailed information about the training, during the whole process.

The tool opens a collaboration channel between data scientist and decision-making individual in the production line, involving people assigned to specific tasks.

Deep Learning models can make wrong decisions, may it be due to change of conditions in the production line or just a type of data the model has never seen before. To reduce the number of wrong predictions, the system allows to retrain the model with newly acquired data, labelled by a human expert.

The tool is part of Kolektor Digital Platform and covers deep learning stage of the pipeline. It takes the form of a graphical user interface (GUI) and gives users the ability to modify the models and train them on custom image data. Simple design and user-friendly GUI makes the whole process from labelled data to fully functioning model fast. The tool is being designed in a way that makes deep learning as easy as possible. It integrates multiple visualization methods, to help operator make informed decisions, increase productivity, and make the entire process efficient.

	Participant	KOL
	Technology name	Kolektor Digital Platform: Kis DeepLearning
	Brief description	Tool to train deep learning models. Easily annotate, create and analyse datasets. It provides user friendly model creation, training and analysis of trained models.
Processes	**Supervision**	Operator can view and inspect created datasets. During the process of model training, operator can monitor current state and detailed information of the training process.
	Investigation	Operator can analyse the dataset, quickly inspect and modify the labels if necessary.
	Prescriptive guidance	
	Predictive support	Based on the model analysis and evaluation on a subset of images, the operator can get insight into what would happen in the future if we were to observe similar products in the production line.
	Collaborative	The tool allows collaboration of multiple people, each assigned to a specific task. The whole process could be split into subtasks - acquiring images on the production line, human expert labelling the images (classification, anomaly...), data scientist training the model on new dataset and at the end evaluation of the model and pushing the new (improved) model to the production line.
Tool category	**AR/VR/MR/XR tools**	
	Simulation tools	Given the data from a current process on the production line we can simulate what the changes we have made to our model will do to future processes. The simulation results will help human expert with decision to update the model in the production or make more changes to the model.

	Engineering/design tools	GUI provides functionalities such as 1.) Dataset creation, data labelling, visual dataset analysis; 2) Model creation, Model fine-tuning, Model training visualization and visual model analysis.
	Information presentation tools	Information is conveyed through the graphical user interface and can be accessed through any device that has web browser support. For full functionality of the tool, such as training and model analysis, it is encouraged that a graphics processing unit (GPU) is available on the device.
	Methodologies	Since the tool is part of a Vision System, human expert has to follow various Machine Vision standards defined in VDI/VDA/VDMA2632. Due to resource limitations, we cannot afford to use autoML methods to create optimal datasets without human operator, so the tool includes methodologies for data analysis and visual representations.
	Collaboration/co-engineering	The entire processes of retraining a model requires multiple experts in different fields. From acquiring new data, labelling the images, analysing the data to creating a new model, analysing the results and simulating future processes. Each task needs a person with different knowledge and skills. Our tool enables collaboration between operators from different fields and reduces the gap between line worker and data scientist.
Phase	**R&D/Design/ engineering**	
	Procurement/Plant implementation	Computer Vision is a key enabling technology in the PQ and CQ inspection systems of the ZDM paradigm.
	Manufacturing	Computer Vision is a key enabling technology in the AQ inspection systems of the ZDM paradigm.
	Service	
Test & validation	**Pilot, WP**	KOLEKTOR, WP6/WP7
	Where	In the scope of WP6 and the JSI RECON experimental facility KiS is primarily used as a data acquisition and early analysis tool. In the scope of WP7 the whole solution is being tested in a production environment, where we have a running system on the shop floor.
	Human Centric ZDM relevance	Deep Learning part of the Kolektor Digital Platform was initially based on the open-source NVIDIA Deep Learning GPU Training System (DIGITS). We took forked version 4QuantOSS/OpenDIGITS with python3 support and no Caffe framework and extended it to fit the needs of our Digital Platform.
	Prototype plan	Tool is available, but not in its final version.
	Supported APIs	Tensorflow Serving model

Kolektor Digital Platform: KiS Framework (KOL)

KiS 4 is a framework, capable of delivering flexible applications using various components such as vision, machine learning, communications, and robotics. It offers a web-based user interface providing relevant information, allowing inspection and corrective actions, controlling the whole process.

It includes a visual programming tool that allows you to create application recipes, based on OPC UA Vision specification, through a web-based diagramming interface that enables data collection, aggregation, and analysis.

It allows and promotes collaboration between engineers and data scientists, which can modify the same application and act on its execution workflow and final effectiveness.

	Participant	KOL
	Technology name	Kolektor Digital Platform: KiS Framework
	Brief description	KiS 4 is a framework, capable of delivering flexible applications using various components such as vision, machine learning, communications and robotics.
Processes	**Supervision**	Relevant information for the vision application will be shown via web-based dashboard.
	Investigation	Dashboard will allow to inspect results and trigger corrective measures.
	Prescriptive guidance	Application dashboard will visualize possible problems and enable person to take corrective actions if applicable.
	Predictive support	Application, via dashboard, reports current status. These empower the operator to correct displayed results and provide feedback to future AI model training.
	Collaborative	Corrective measures triggered by operator will enable data scientists to train and implement better AI models.
Tool category	**AR/VR/MR/XR tools**	
	Simulation tools	Software will provide data mocks which enable simulation of the application. Hardware like cameras and various IO devices can be simulated via mock replacements.
	Engineering/design tools	KiS Framework is a tool which via visual programming allows construction of application recipes (concept based on OPC UA Vision specification). It is implemented as a web diagramming GUI which allows for data acquisition, aggregation and processing. Once application is constructed, GUI allows generation of visual dashboards that show continuous results of running application.
	Information presentation tools	Reporting features are enabled via web-based dashboard. It consists of various widgets that allow for visual representation of application data.
	Methodologies	Application implementation follows best Continuous Integration/Delivery practices, with code versioning and reviewing. Development is iterative with bi-weekly validation against acceptance criteria.
	Collaboration/co-engineering	Web-based GUI interface allows for easy access and collaboration among peers. Different engineers and data scientists can modify same application and collaborate on its execution workflow and final effectiveness.

Phase	R&D/Design/ engineering	
	Procurement/Plant implementation	The tool is used to capture RAW data and feed it to the AI application.
	Manufacturing	The tool is used to collect raw image data, process it through AI pipeline and report results. GUI will enable process monitoring.
	Service	
Test & validation	Pilot, WP	KOLEKTOR, WP6/WP7
	Where	In the scope of WP6 and the JSI RECON experimental facility KiS is primarily used as a data acquisition and early analysis tool. In the scope of WP7 the whole solution is being tested in a production environment, where we have a running system on the shop floor.
	Human Centric ZDM relevance	An application recipe needs to be constructed; GUI dashboard widgets need to be implemented based on pilot specification.
	Prototype plan	KiS FW and GUI already exists. Attached image for proto application.
	Supported APIs	OPC UA, MQTT, REST, WebSocket, ProtoBuffers, Apache Kafka

Data Analysis tool (SYN)

The main goal of the tool is to process a set of KPIs that are representative of the process quality and that can support the operator in the identification of roots for possible problems in the quality of the manufactured parts.

The overall system will be developed by different partners involved in the PRIMA pilot. SYN will focus on the development of an analytics tool to elaborate a set of KPIs based on the data monitored, which will be exploited, on the one hand, by the operators to evaluate and get insight about the manufacturing process and, on the other hand, by a Decision Support System (DSS) for further elaboration and the triggering of possible corrective/preventive actions.

The Data Analytics Tool actively contributes to the process of managing the quality of the production process, in cooperation with the other components of the overall system, each specialized on their functionality. A relevant innovative role of the Data Analytics tools is represented by the aggregation of information produced by different sources, collected by leveraging the widely accepted standard MQTT to simplify communication and semantic issues

	Participant	SYN
	Technology name	Data Analysis tool
	Brief description	A tool to aggregate info from different sources (machine and other tools) and elaborate relevant KPIs.

Processes	Supervision	Management functionalities are provided, to organize the production flow and to keep it under control.
	Investigation	
	Prescriptive guidance	
	Predictive support	
	Collaborative	
Tool category	AR/VR/MR/XR tools	
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	A web based user interface provides reporting and supervision functionalities.
	Methodologies	
	Collaboration/co-engineering	
Phase	R&D/Design/ engineering	
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during the manufacturing of parts with the PRIMA additive machine tool.
	Service	The tool collects the process parameter from the machine tool and can highlights when some KPIs overcome pre-configured thresholds, triggering the need for a maintenance task.
Test & validation	Pilot, WP	PRIMA, WP7
	Where	In the scope of PRIMA pilot the tool will mainly act as a coordinator of information collected by other partners in the system, providing a user interface to present and manage it. Il will be tested against a 3D printing sample production.
	Human Centric ZDM relevance	The application is developed from scratch based on the requirements identified for PRIMA pilot.
	Prototype plan	End 2021, as it strongly depends on the development of the other tools in the same configuration.
	Supported APIs	MQTT+JSON

Decision Support System (IMECH)

The component is a general-purpose tool to develop algorithms, aiming at supporting data analytics and modelling.

The component is applied to move a qualitative approach in a quantitative one, thanks to the development of data analytics methodologies which are based on data collected from the field.

	Participant	IMECH
	Technology name	Decision Support System (DSS)
	Brief description	The DSS's specifications are still to be defined. In general, this tool should provide the information coming from MPFQ analysis in order to provide the corrective actions to improve the quality of the processes
Processes	Supervision	The information can be exploited by the process supervisor to identify critical stations and to define corrective actions to improve the e quality of manufacturing processes.
	Investigation	
	Prescriptive guidance	
	Predictive support	
	Collaborative	
Tool category	AR/VR/MR/XR tools	
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	The reporting functionalities or a dashboard provides information to the user.
	Methodologies	
	Collaboration/co-engineering	
Phase	R&D/Design/ engineering	
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during the manufacturing of dryers in the assembly line.
	Service	
Test & validation	Pilot, WP	WHR, WP7
	Where	The Decision Support System will be validated in the Whirlpool pilot and, specifically, considering the Lodtz plant where dryers are assembled. Currently, a validation plan is not available yet, but Whirlpool pilot partners are working on the definition of 1-2 use cases.
	Human Centric ZDM relevance	The application is developed specifically for the Whirlpool pilot.
	Prototype plan	Probably at the end of 2021 a DEMO of the DSS tool will be operative in the plant.
	Supported APIs	HTTP REST + JSON

Qu4lity trend cockpit (TTS)

The main purpose is to support management level decisions to improve product and process quality. This cockpit allows to visualize trends of key quality indicators and quantitative measures in a graphical way to increase awareness for critical situations and to detect any area of improvement

	Participant	TTS
	Technology name	Quality trend cockpit
	Brief description	The main purpose is to support management level decisions to improve product and process quality. This cockpit allows to visualize trends of key quality indicators and quantitative measures in a graphical way to increase awareness for critical situations and to detect any area of improvement
Processes	Supervision	Graphical visualization of Key quality trends
	Investigation	
	Prescriptive guidance	
	Predictive support	
	Collaborative	
Tool category	AR/VR/MR/XR tools	
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	The cockpit provides information on some key quality aspects
	Methodologies	
	Collaboration/co-engineering	
Phase	R&D/Design/ engineering	
	Procurement/Plant implementation	
	Manufacturing	The cockpit will be used to monitor the quality performances of the dishwasher assembly plant in Poland
	Service	
	Pilot, WP	WHR, WP7
	Where	The Qu4lity trend cockpit will be validated in the Whirlpool pilot and, specifically, considering the Lodtz plant where dryers are assembled. Currently, a validation plan is not available yet, but Whirlpool pilot partners are working on the definition of 1-2 use cases.
	Human Centric ZDM relevance	This application will be developed by scratch and it will be based on Grafana technology
	Prototype plan	mid 2021
	Supported APIs	MQTT+JSON

Pacelab WEAVR (PACE)

Pacelab WEAVR is a powerful software suite to streamline the authoring, management and execution of extended reality (XR) applications for operations, maintenance and training. Pacelab WEAVR enables the creation, deployment and execution of a wide array of virtual, augmented and mixed reality solutions from the same set of technical data, creating a seamless and consistent experience from basic familiarization exercises to advanced, interactive field support.

Pacelab WEAVR provides an integrated set of modules including an editor platform, a server application for collaboration and content distribution, as well as a run-time environment empowered by mixed, virtual, and augmented reality technology.

Its unique set of features and modules enables companies to create, manage, and implement a wide array of operation (setup, maintenance, etc.) and training applications from the same set of technical data, creating a seamless and consistent experience from basic familiarization exercises to advanced, interactive shop floor and field support.

The solution is designed for subject matter experts to easily create content; for trainees and long-term employees to acquire new know-how and skills and get assistance for their day- to-day assignments; and for supervisors and instructors to monitor and support these activities.

The **Pacelab TWIN** system can be integrated with Pacelab WEAVR in order to enhance the virtual factory with complex simulated scenarios also including machine problems, procedure-based scenarios and AR data visualization. Pacelab TWIN is a powerful software toolbox to streamline the design and development of digital twin in Virtual Reality. It provides an integrated authoring platform, which supports the entire production process from scene definition (3D machineries, production lines, etc.) to management of production simulation and events (virtual sensors, cloud IOT brokering, analysis and actuation) to final delivery. Pacelab TWIN enables the creation of a wide array of virtual copy of existing or future systems, creating a seamless and consistent copy to be used for evaluation of the current system, if-cases scenarios, workers training and evaluation of changes.

Participant	PACE
Technology name	Pacelab WEAVR
Brief description	Pacelab WEAVR is a powerful software suite to streamline the authoring, management and execution of extended reality (XR) applications for operations, maintenance and training. Pacelab WEAVR enables you to create, deploy and execute a wide array of virtual, augmented and mixed reality solutions from the same set of technical data, creating a seamless and consistent experience from basic familiarization exercises to advanced, interactive field support. Its template-based, visual approach requires little

		to no programming or scripting skills, allowing subject matter experts to model tasks and procedures efficiently and without involving 3D developers or software engineers.
Processes	Supervision	
	Investigation	
	Prescriptive guidance	Augmented operational support & maintenance using guided visualizations and annotations via Pacelab WEAVR. In case new faulty error has been detected, it will trigger a troubleshooting procedure that will provide interactive guided support to the operator with the actions necessary
	Predictive support	
	Collaborative	Through the WEAVR Manager web interface, the team lead/Manager will be able to communicate and collaborate with operators to provide additional guidance where needed.
Tool category	AR/VR/MR/XR tools	Using AR technology like HoloLens & mobile devices will be used to entail human in the loop of ZDM
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	Through the WEAVR Manager web interface, operators and managers are able to observe the overall performance & analytic data about the operational procedure
	Methodologies	
	Collaboration/co-engineering	
Phase	R&D/Design/ engineering	
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during the assembly/machinery setup stage.
	Service	The tool will be exploited when the maintenance task is triggered as well when sales services are needed.
Test & validation	Pilot, WP	Continental, WP6/WP7
	Where	Pacelab WEAVR is being tested at Polimi facility under the scope of WP6 as well will be validated with Continental Pilot under scope of WP7, in a shop-floor at Ingolstadt plant.
	Human Centric ZDM relevance	The WEAVR Manager web interface enhanced and updated to meet the requirements of Continental Pilot, as well developing new features into the WEAVR Creator & Player
	Prototype plan	An Early prototype of Continental's use case has been released, by end of August 2020 Continental will a functional AR step by step guidance application ready for test on the shop-floor. The WEAVR Manager MVP has been released as an early prototype to be tested internally, probably by end of mid Oct 2020 will be able test the deployment with Continental.

	Supported APIs	JSON , MQTT

Design4AM – Interactive Visualization solution (FHG-IGD)

This solution offers a hardware accelerated interactive visualization of in-line sensor data gathered from an additive manufacturing process. Using data analytics algorithms, data patterns potentially causing defects will become visually apparent.

In-line sensor systems in the context of ZDM for additive manufacturing processes produce large amounts of volumetric data in a layered fashion. This solution interactively visualizes these data to reveal specific patterns for events that can potentially cause defects. Utilizing the CAD-model of the fabricated component and data analytics algorithms, the huge set of sensor data is compressed without missing important information. Finally, hardware acceleration techniques enable the interactive visualisation of sensor data together with a virtual model of the component. In QU4LITY our background tool will be extended by hardware accelerated interactive visualization solutions which will be coupled with data analytics algorithms. The data analytics algorithms will operate on machine data and in-line process information in order to identify undetected correlations between the product quality and corresponding influencing factors. The correlations will be mapped on visualization structures and will visually reveal specific patterns for events that can potentially cause defects.

	Participant	FHG-IGD
	Technology name	Design4AM
	Brief description	This tool provides a volumetric visualization of in-line sensor data gathered from an optical sensor device that is built in a powder bed fusion machine. More precisely, the sensor data in the PRIMA pilot consist of pictures taken for each powder bed layer where each pixel values measure the roughness of the powder bed.
Processes	Supervision	An interactive and intuitive GUI helps the machine operator to analyse the criticality of the ongoing manufacturing process
	Investigation	The operator can explore the data set via 3D GUI navigation to investigate areas of further interest
	Prescriptive guidance	
	Predictive support	
	Collaborative	
Tool category	AR/VR/MR/XR tools	
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	An interactive GUI is the core to the volumetric data visualization
	Methodologies	

	Collaboration/co-engineering	The operator can give optional feedback about the criticality of the current powder layer which can be further processed, e.g. in a decision support system
Phase	R&D/Design/ engineering	
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during the manufacturing of parts with the PRIMA additive machine tool.
	Service	
	Pilot, WP	PRIMA, WP7
	Where	In the context of the PRIMA pilot, the system will be validated against a sample production.
	Human Centric ZDM relevance	During development, the original technology used in Design4AM turned out to not fit all requirements present in the PRIMA pilot. Therefore, the application has to be build from scratch.
	Prototype plan	Probably between beginning and mid 2021
	Supported APIs	MQTT, JSON, HDF5

Manual work support via AR (SpaceAR) (VTT)

This technology leverages the Augmented Reality to support the worker for better understanding of the process/production status and to provide guidelines for critical manual tasks. The worker is supported by means of step-by-step information and warnings. The system is based on table/phone devices or head mounted displays (e.g. HoloLens) and supports the integration of worker data (collected with 3D cameras and sensors) to AR system (see figure). The use of worker data is exploited to improve the worker task performance and decrease the number of errors.

	Participant	VTT
	Technology name	Manual work support via AR (SpaceAR).
	Brief description	AR based high-knowledge and / or critical work support via AR. Worker will have better situation awareness of process and will have current information, in right time in correct location.
Processes	Supervision	The information presented to the user via AR enable the operator to supervise the correct functioning of a machine/production line.
	Investigation	
	Prescriptive guidance	The operator is supported with information and instructions useful for the task to be accomplished
	Predictive support	
	Collaborative	
To	AR/VR/MR/XR tools	AR tools presents the information to the user utilising a HoloLens 1/2 and/or handheld device

	Simulation tools	
	Engineering/design tools	
	Information presentation tools	AM machine process awareness with augmented information
	Methodologies	
	Collaboration/co-engineering	
Phase Autonomous	R&D/Design/ engineering	
	Procurement/Plant implementation	
	Manufacturing	The tool will be exploited during the maintenance and process monitoring
	Service	
Test & validation	Pilot, WP	PRIMA, WP7
	Where	Second version: Lab tests in in SMACC experimental facility - M29 / End-user tests at PRIMA pilot's premises – M33 Third version: Lab tests in in SMACC experimental facility – M36 / Final end-user tests at PRIMA pilot's premises – M39
	Human Centric ZDM relevance	Interfacing to AM machine process control and video feeds via MQTT or relevant standard interface
	Prototype plan	The first prototype has been tested 02/20 and second version probably ready on mid 2021
	Supported APIs	JSON , MQTT

Pseudo Error Reduction (TUDO)

The increasingly demanding of high-quality electronic components forces companies to fulfil a high number of inspection gates, with high inspection severity, which in turn procures a high number of pseudo defects.

Double inspections by process experts reduce the aforementioned defects, as they develop process know how. However, the evaluation requires a high level of expertise and high inspection costs. Autonomous learning inspection based on machine learning algorithms could enable product inspections with a high degree of inspection severity.

By implementing the module, various interaction possibilities between humans and the module arise: The actual state of production (e.g. counts of errors and locations with higher error amount) can be visualised within a dashboard. From this, process experts can derive information for process improvements and evaluate historical process developments. Furthermore, process experts can evaluate the module regarding its topicality, for example, to verify its function after process adjustments have been made.

	Participant	TUDO
	Technology name	Pseudo Error Reduction
	Brief description	Based on the monitoring of normal process behaviour and reliable detection of pseudo faults, correlations between process changes and upstream production steps are automatically identified. From this, process adaptations such as changes in monitoring limits can be derived.
Processes	**Supervision**	Actual state of production (e.g. counts of errors and locations with higher error amount) will be visualized within a dashboard
	Investigation	
	Prescriptive guidance	
	Predictive support	
	Collaborative	Humans are needed to verify whether the technology still fits the actual state or to identify changes in the production line
Tool category	**AR/VR/MR/XR tools**	
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	The reporting functionalities or a dashboard provides information to the user.
	Methodologies	The reporting functionalities can be used to optimize the process
	Collaboration/co-engineering	
Phase	**R&D/Design/ engineering**	
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during the Solder Paste Inspection within the SIEMENS production line.
	Service	
Test & validation	**Pilot, WP**	SIEMENS, WP7
	Where	
	Human Centric ZDM relevance	The application is developed from scratch based on the requirements identified for SIEMENS pilot.
	Prototype plan	beginning of 2021 for a prototype of the analytics tool, at the SIEMENS Pilot
	Supported APIs	

Shopfloor visualisation (TUBS)

MR opens new ways of interacting with technical systems. At the heart of MR application on the shop floor lies a backend software implementation connecting visualization and input devices (e.g. HMD, speech interpreters) with machine and productions system data through suitable interfaces.

With MR, natural user interfaces using for instance voice or gesture controls can be brought to application on the shop floor. In the scope of QU4LITY a MR shop floor management concept will be developed, and different functionalities will be designed to ensure a zero-defect management.

The diverse augmented and virtual reality devices will be used for visualization of digital data as three-dimensional augmentations and the integration into spatial context, integration of a feedback and quality assurance system, designing a predictive maintenance and quality documentation and the implementation of a manufacturing fingerprinting protocol.

	Participant	TUBS
	Technology name	Visualization of product characteristics (e.g. failure) information
	Brief description	The human operator can monitor a set of information relevant for his work and gets additional information regarding product characteristics (e.g. failures) and prediction of product behaviour within manufacturing system
Processes	**Supervision**	A dashboard will visualize the relevant information about the current product features at a certain station
	Investigation	
	Prescriptive guidance	
	Predictive support	The operator will be provided with information on the propagation of the current features / failures to the downstream stations
	Collaborative	
Tool category	**AR/VR/MR/XR tools**	A MR tools presents the information to the user utilising a HMD or handheld device
	Simulation tools	
	Engineering/design tools	
	Information presentation tools	A dashboard presents the visualized information to its user
	Methodologies	
	Collaboration/co-engineering	
Phase	**R&D/Design/ engineering**	
	Procurement/Plant implementation	
	Manufacturing	The tool is exploited during the manufacturing of parts within the tool
	Service	

Test & validation	Pilot, WP	Continental, WP7
	Where	The technology it is expected to be validated in the CONTINENTAL pilot
	Human Centric ZDM relevance	A generic application is built from scratch and adapted to the requirements identified at Continental
	Prototype plan	mid 2021
	Supported APIs	

IEC-61499 IDE and runtime platform (NXT)

The core enabling component provided by nxtControl in QU4LITY is the automation platform resulting from the evolution of the IEC-61499 standard. By adding innovative features on top of the existing industry-ready functionalities, such a solution is conceived to satisfy all the requirements of intelligent manufacturing systems with distributed intelligence envisioned by Industry 4.0. The platform exploits the interoperability of the standard to guarantee functional independence from the specific hardware used to execute the control logics as much as to sustain compatibility between controllers of different producers. The IDE of the platform is based on the FBs paradigm of the IEC-61499 and it finally brings the concept of "automation object-orientation" to the development of control applications, as much as the ease of hierarchization.

The IEC-61499 platform is a fully functional reference implementation of the standard, composed of the following key elements: 1) An object-oriented Integrated Development Environment (IDE), fully compliant with the new evolution of the IEC-61499, where developers of single CPS and/or of the orchestrating intelligence governing the behaviour of their aggregation will be capable of designing complex applications with ease, exploiting the abstraction layers and programming methodologies that the standard automation language proposes. 2) An IEC61499-based runtime that manages, transparently to the developer, fundamental functionalities such as: event-based communication between separate controllers; strict real-time clock synchronization among the IEC-61499 network; near-real-time bidirectional connectivity to the in-Cloud behavioural models of the CPS.

	Participant	**NXT**
	Technology name	IEC-61499 IDE and runtime platform
	Brief description	The NxTTech IDE and EcoRT are based on the IEC 61499 standard12 [11]. IEC 61499 is a standard for modelling distributed control systems for use in industrial automation. Its event driven execution model allows an explicit specification of the execution order of Function Blocks (FBs). The FB of IEC 61499 is an abstraction that represents a component, which is usually implemented in the form of software but can also take the form of hardware

[1] https://www.iec61499.de/
[2] https://en.wikipedia.org/wiki/IEC_61499

Processes	Supervision	The IEC61499-based runtime implements the fundamental functionalities of the system offering an HMI for an interactive supervision
	Investigation	
	Prescriptive guidance	
	Predictive support	
	Collaborative	
Tool category	AR/VR/MR/XR tools	
	Simulation tools	
	Engineering/design tools	The IDE of the platform is based on the FBs paradigm of the IEC-61499 and it finally brings the concept of "automation object-orientation" to the development of control applications, as much as the ease of hierarchization.
	Information presentation tools	
	Methodologies	The platform exploits the interoperability of the standard to guarantee functional independence from the specific hardware
	Collaboration/co-engineering	
Phase	R&D/Design/ engineering	The object-oriented Integrated Development Environment (IDE) enable the design of complex applications with ease, exploiting the abstraction layers and programming methodologies that the standard automation language proposes.
	Procurement/Plant implementation	
	Manufacturing	The IEC61499-based runtime provides an HMI to support the operator
	Service	
Test & validation	Pilot, WP	ASTI (AGV), WP7
	Where	
	Human Centric ZDM relevance	
	Prototype plan	
	Supported APIs	

Additive manufacturing simulator (TTS)

Within the scope of QU4LITY, a software tool to simulate the metal additive manufacturing process based on the powder bed fusion system will be developed. This tool will support human operators in the investigation process to find out the best trade-off between production costs and final product quality. The additive manufacturing simulator will provide a quick and reliable production time estimation starting from a set of input parameters, the placement of parts in the work area and the selected printing strategy. The simulation results will help and drive human operators in setting up the input parameters and the printing strategy to get the final product with the quality required by customers.

The additive manufacturing simulator will allow:

- To simulate the printing process of different parts in the same work area based on the powder bed fusion technology
- To import the printing program and input parameters
- To be connected to the additive machine to read machine configuration

	Participant	TTS
	Technology name	Additive manufacturing simulator
	Brief description	The tools simulate the metal additive manufacturing process based on the powder bed fusion system
Processes	**Supervision**	
	Investigation	The additive manufacturing simulator will provide a quick and reliable production time estimation
	Prescriptive guidance	The simulation results will help and drive human operators in setting up the input parameters and the printing strategy to get the final product with the quality required by customers.
	Predictive support	The simulation allows to predict possible defects in the printing process and to suggest possible improvements.
	Collaborative	
Tool category	**AR/VR/MR/XR tools**	
	Simulation tools	The tools simulate the metal additive manufacturing process based on the powder bed fusion system
	Engineering/design tools	The tools assist the last phase of the design process, supporting the optimal programming of the printing machine
	Information presentation tools	
	Methodologies	
	Collaboration/co-engineering	
Phase	**R&D/Design/ engineering**	
	Procurement/Plant implementation	
	Manufacturing	The simulation could immediately precede the production process, so actually supporting it.
	Service	
Test &	**Pilot, WP**	PRIMA, WP7
	Where	In the context of the PRIMA pilot, the system will be validated against a test production.
	Human Centric ZDM relevance	The tool is driven by a design operator

	Prototype plan	mid 2021
	Supported APIs	MQTT+JSON

7. Conclusions

This deliverable describes the final results and detailed approach of T5.1 in the development of a Framework to support the specification/integration of human centric AQ processes.

The activities of T5.1 in its initial part focused on identifying the most relevant elements that play a role in the implementation of autonomous ZDM processes that entail humans in the loop. During its subsequent development, the task followed a progressive and iterative approach, refining step by step an organic vision of the several aspects involved by the entailing of humans in the loop, both from the technological and functional perspective.

Overall, this report clarifies the concept of human-in-the-loop ZDM processes and proposes a classification for the different types of ZDM processes entailing humans in the loop. Such a tentative to classify those processes is based on the type of information flow that is involved in the interaction between the human operator and the tools/technologies adopted to achieve the desired quality performance for the product/production process of interest.

To provide a proof-of-concept of the proposed framework, this document presents a list of technologies and tools developed by the QU4LITY project, which enable the implementation of ZDM processes entailing humans in the loop. Their presentation was mapped against the developed template, with the twofold objective to validate the framework against practical cases and to support further development of ZDM technologies entailing human-in-the-loop.

8. References

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List of figures

List of Abbreviations

Abbreviation	Explanation
AI	Artificial Intelligence
AQ	Autonomous Quality
AR	Augmented Reality
CPPS	Cyber Physical Production System
CPS	Cyber Physical System
HITELZ	Human-In-ThE-Loop ZDM
KPI	Key Performance Indicator
ML	Machine Learning
MPFQ	Material Process Function Quality
MPP	Multi-process preparation
MR	Mixed Reality
RA	Reference Architecture
VR	Virtual Reality
XR	Extended Reality
ZDM	Zero Defect Manufacturing

Partners: