UNIVERSITÀ
DI PARMA

UNIVERSITA' DEGLI STUDI DI PARMA

DOTTORATO DI RICERCA IN
INGEGNERIA INDUSTRIALE

CICLO XXXII

DESIGN, DEVELOPMENT AND APPLICATIONS OF A LEARNING FACTORY AT THE UNIVERSITY OF APPLIED SCIENCES AND ARTS OF SOUTHERN SWITZERLAND

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Anni 2016/2019

Abstract

As the manufacturing industry is moving its steps towards a more digital, smart and flexible scenario, the changes required to achieve the expectations of the Industry 4.0 (I4.0) framework are numerous and extensive. Though, a general lack of understanding of how new technologies could be integrated and shall be implemented is present, limiting the rate of adoption of such changes and the related beneficial impacts.

This thesis describes the design and implementation of a learning factory at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) aiming at filling the gap in I4.0 related skills development thorough a learning by doing approach, and providing a research platform that could foster collaboration of practitioners and academia on the development and testing of new technologies.

The developed factory features a modular approach and, in its current set-up, integrates different production technologies such as additive manufacturing, laser processing and milling. These technologies are installed for the current pilot production, a highly customizable item consisting in a TANGRAM game-set packaged into personalized boxes. The entire factory is coupled with its digital twin, which is fed by an exhaustive monitoring infrastructure composed by vision systems and high precision measurement instruments, allowing to track in real time plant processes.

The design has been carried out in order to make the learning factory serving as a mean to face both educational and research challenges at many different levels. As an educational mean, students and professionals have the chance to dive into manufacturing history experiencing both classical automation topics (PLC, MES and SCADA programming, precision axes control and pneumatics), as well as modern

technologies, typical of the most advanced smart-factories (IoT, vision systems, simulation and digital twin, advanced measuring methods and smart production management systems).

From a research point of view, the factory serves as a pilot plant for internal research and applied industrial projects, on the top of which applications, manufacturing methods and technologies are developed, tested and integrated.

Furthermore, the factory allows for a practical technology transfer process between university and industry. In fact, it allows to test new technologies that, in a second moment, can be integrated in the real manufacturing plant and, also, it serves as a showcase allowing to show and measure in a realistic environment the advantages brought by more advanced solutions or approaches.

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1. Introduction

1.1. Background

Switzerland is set to remain one of the leading countries in the development and application of advanced and high value added products. In order to achieve this goal, it is mandatory to evolve its manufacturing infrastructure towards the most advanced and efficient technologies available, with a special focus on the industry 4.0 paradigm, as well as to develop new and optimized manufacturing strategies towards a more and more efficient approach.

Towards these goals, a lot of different parties are actively playing a role in the country:

- **The federal government**, which is founding many frameworks in different areas towards this ultimate goal (for example the Innosuisse ”impulse program”, dedicated to the technology transfer in the field of digitalization);
- **Industry**, which is very active and interested in the concepts of industry 4.0 and thus is massively investing in this direction;
- **Universities**, where many new fields of research are being born and are actively being pursued with a multitude of research projects covering all the different aspects of the I4.0 revolution.

This is the context in which the SUPSI learning factory has been born, aiming to tackle a set of problems that, as a university, need to be faced on a daily basis:

- **Education:** One of the most frequent requests that companies express to universities is that they would like to receive newly formed engineers with a more practical knowledge, related to the actual challenges they will have to face once graduated and start to work. This is especially true for management engineering, where, historically, there has been a lack of laboratories and of practical education activities in general.

The solution of this issue is one of the main goals of the SUPSI learning factory, which has been developed with the precise goal of giving an actual hands-on educational experience to students on different topics: automation, production management, production scheduling, logistics, mechatronics, etc.

- **Research:** When working on research projects, it is often difficult to access real manufacturing plants in order to test and keep developing the projects contents, and this is true in many different areas whether we are developing new approaches, concepts, software or machines. In fact, even if in most projects there is one or more industrial partner involved and thus interested in its developments, it is also true that it would often be necessary to momentarily stop or modify daily operations in their manufacturing plants in order to most effectively carry on research, but this is obviously very costly and complicated. This situation, in most cases, results in very limited time dedicated to practical testing which limits the effectiveness of the research being carried on.

  The SUPSI learning factory addresses this issue by means of giving researchers a realistic environment based on an open architecture and built with industrial grade components where many industrial case studies can be reproduced allowing for unlimited and realistic testing campaigns.
- **Technology transfer:** Digitalization turns out to be extremely critical for SMEs. In fact, technologies and knowledge connected to digitalization are affordable and quite easily reachable, but the identification of the most suitable ones and the development of a digitalized system for each specific

use case still represent a big challenge for them. SMEs, i.e. companies with less than 250 employees, account for over 99% of companies in Switzerland and create two-thirds of the jobs in the country. In particular, Ticino, where SUPSI is located, represents the region with the highest percentage of SMEs with ca. 35’000 companies and more than 150’000 employees. (data from STATENT).

The SUPSI learning factory aims at becoming a kind of Gymnasium, where local (and non-local) manufacturing SMEs explore i4.0 technologies and their advantages, and experience the first combinations of i4.0 with their existing machines, devices and procedures.

This happens in a comprehensive but, still, protected and guarded environment, easily accessible thanks to the open-access protocol adopted to deal with the pilot digital backbone, and affordable also for small companies, novel to the topic. This allows them to fail, retry and adjust. Namely: learning, under the guidance and support of experienced scientists. Thanks to the SUPSI learning factory, SMEs will benefit of digital manufacturing advantages in a much shorter time and with an affordable effort.

1.2. State of the art

The Learning Factory is a practice-based curriculum and physical facilities for product realization. Its goal is to provide an improved educational experience that emphasizes the interdependency of manufacturing and design in a business environment [1].

The concept of the learning factory dates back to 1994 when the first grant to design and build one was awarded to Penn state university [2]. This early concept of the learning factory focused on a more hands-on education with the aim for engineers to experience real-world industrial issues both regarding manufacturing as well as design [3] [4] [5]. Since then, many other universities followed [6] and the concept of learning factory evolved a lot during the years, driven by the new industry 4.0 revolution.

The industrial world is facing many challenges, which range from the integration of new technologies to volatile business environments. This requires them to quickly adapt to the new conditions and, therefore, they need to rely on their employees capabilities [7]. In this area, traditional teaching methods have shown limited effects [8], leaving universities with the task of identifying new teaching approaches and new job profiles and correlated requirements. In particular, industry requires an interdisciplinary and practical training, requiring a more hands-on approach to universities.

In general, companies need to react with short-cycle adaptation, a stronger customer focus and shrinking batch sizes [9] [10]. The continuous advancements of information and communication technologies offer great potential to manufacturing companies. The term Industry 4.0 embraces the use of new communication technologies and accelerates the implementation of cyber-physical systems in the manufacturing industry [9] [11]. Industry 4.0 has a big influence on employees and organizations across technical innovations in production [12]. The production work will change in that manual operations in production will decrease while steering and monitoring activities will become more important [13]. The staff needs to be prepared for the changed job profile by getting acquainted with new technologies. In order to enable this continuous adaptation to rapid changes, academia and manufacturing industry must work together in an appropriate environment.

Learning factories have demonstrated to be an example of a proper ecosystem where hands-on education, research and technology transfer between academia and industry happens. The label “learning factory” with the composition of the two words “learning” and “factory” is to be used for systems that address both parts of the term – it should include elements of learning or teaching as well as a production environment [14]. Learning factories have already been used in practical trainings for different topics within production processes during the past years (e.g. lean management and resource efficiency) [15]. Furthermore, learning factories offer a realistic environment of production systems by the use of their technical equipment. In addition, process improvements and modifications can be safely tested during production processes [16]. Therefore, learning factories offer a great opportunity for trainings and the preparation of employees for the use of Industry 4.0 [17]. To achieve these goals, learning factories 4.0 must include a pervasive use of key digital technologies; which can concretely be summarized into three main clusters [18]:

- **Connectivity:** enabling the flow of relevant information to the right decision makers in real time. Examples include digital performance management and the use of augmented reality to communicate interactive work instructions.
- **Intelligence:** applying advanced analytics and artificial intelligence to an array of data to generate new insights and enable better decision making. Examples include predictive maintenance, digital quality management and AI-driven demand forecasting.
- **Flexible automation:** leveraging new robotic technologies to improve the productivity, quality, and safety of operational processes. Examples include autonomous guided vehicles, vision systems and using cobots for assembly processes.

On the market, there exist many factory automation modules including some of these technologies; the most popular are solutions from Festo Didactic 4.0. These systems enable technology transfer, university and company level education in many different engineering disciplines, but also consulting activities on Industry 4.0 topics. These solutions are widespread in various universities/research centres and integrated in many different processes, mainly referred to assembly/disassembly operations. Examples comes from SmartFactoryKL [19], iFactory [20], PilotFabrik [21], SmartPro4.0 [22], SwissSmartFactory [23], Industry4.0Lab [24] among many others. Limitations of these kind of modules come from the proprietary technologies and built-in packages that narrow, in many cases, their usage ranges for research and applied research projects purposes. Specifically, most of the real industrial processes cannot be integrated and tested in the aforementioned laboratories, thus technology transfer is just limited at the approach and paradigm implementation of digital manufacturing, missing a complete link with real world companies.

This process turns out to be extremely critical for SMEs [25]. In fact, technologies and knowledge connected to digitalization are affordable and quite easily reachable, but the identification of the most suitable ones and the development of a digitalized system as a whole for each specific use case still represent a big challenge for them.

2. SUPSI Learning factory

2.1. Concept

The SUPSI learning factory has been designed with the aim of creating an open platform, suitable for educational, research and technology transfer purposes. For this reason the factory to encompasses all the different issues that an engineer faces in a real manufacturing environment and takes into account different levels of the automation pyramid.

This led us to decide to start from scratch and self-design the whole plant; in fact, even though many off the shelf solutions exist (e.g. Festo didactic) they all lack in flexibility and customizability. These systems are in fact closed platforms with which is very difficult to interact and which are very difficult to customize to each single project or didactical activity needs. Furthermore we decided that it was of mandatory importance that in the SUPSI learning factory an actual production process needed to be implemented, while, in the above mentioned solutions only the assembly process of a dummy product is usually implemented and, thus, no actual production machine is installed in the plant.

Different areas of interest that were addressed during the development of the learning factory:

- Mechanical design of parts accessories
- PLC programming
- Servo axis dimensioning and tuning
- HMI programming
- Additive manufacturing
- Robotics

- Pneumatic and electric routing
- Safety planning
- Production monitoring
- Production scheduling
- Digital twin

The SUPSI learning factory, of which a brief, introductory description can be found in [26] , creates a reference point for especially Ticino-based manufacturing SMEs that got lost and walking around in need of a digitalization guide.

The SUPSI learning factory advantages will be not limited to the Ticino region, which will be the first and most impacted area, mainly due to the geographical proximity of the pilot, but the results will widespread across the whole country thanks to the contribution of other universities of applied sciences SUPSI collaborates with on a daily basis. A number of projects have already been funded on this topic and SUPSI is already collaborating with several companies and universities.

Moreover, the multipurpose digital manufacturing backbone of the SUPSI learning factory allows for many future research projects in many different fields such as Internet of Things (IoT), augmented reality, cloud computing among others.

2.2. Layout

The SUPSI learning factory has a modular layout of which a schema is reported in Figure 1.

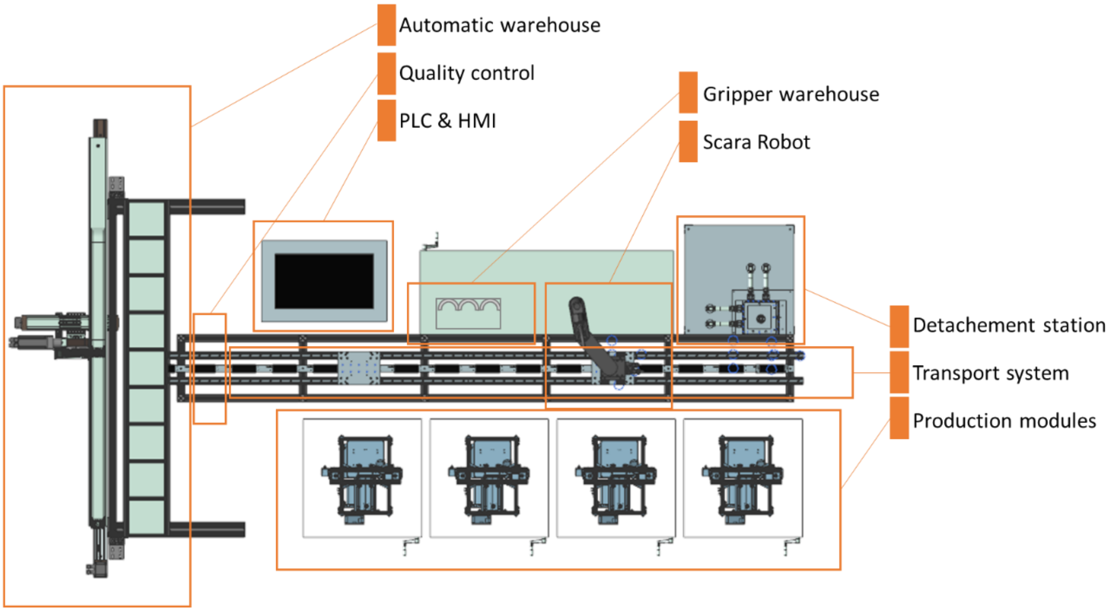


Figure 1 SUPSI learning factory layout

As it can be easily seen, the factory embodies all the different actors which represent the backbone of any modern manufacturing plant:

- **Industrial controllers (PLCs) and human-machine interface (HMI):** basic elements of any automatic machine, necessary to program the behaviour of the machine itself, receive and process data from the installed sensors and allow the operator to interact.
- **An automatic warehouse:** featuring 81 positions and served by a Cartesian robot which loads and unloads each position.
- **Production machines:** at the moment, for the pilot production, additive manufacturing and laser engraving machines are installed in the factory.
- **An advanced transport system:** this system relies on an advanced technology and is equipped with two different carriers, which can be moved independently from one another. The first one is dedicated to the

movement of the different workpieces along the different modules of the factory, while the second positions the robot where needed, allowing it to interact with all the modules of the factory.

- **Quality-testing station:** this station is based on an 2D laser triangulation scanner which, thanks to the interaction with the transport system, allows to obtain the 3D point cloud of any workpiece and perform dimensional analysis, read bar codes, etc.
- **An industrial robot** coupled with an automatic tool changing system: the chosen robot is of industrial grade and can be found in many real manufacturing plants. In the SUPSI learning factory it has the task of loading/unloading the production modules as well as of performing most of the assembling operations. The robot toolhead has been equipped with a pneumatic tool changing system allowing the robot to automatically change its gripper in order to perform the different tasks assigned.

The products as well as the single workpieces are stored on the same pallets (Figure 2) that can hold all the different components thanks to a rubber layer placed on top of it.

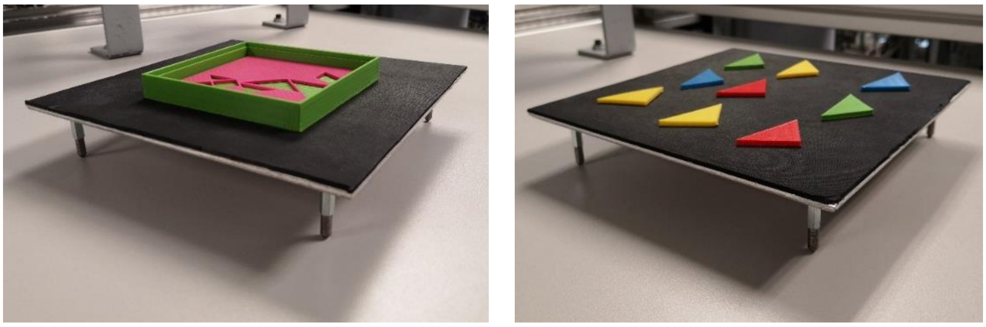


Figure 2 Pallet examples

The presence of all these different actors, especially together with actual production machines, make the SUPSI learning factory a unique laboratory among what can be found in universities in general.

2.2.1. Automatic warehouse

The automatic warehouse (Figure 3) features 81 positions and it is equipped with a three axes Cartesian robot capable of loading and unloading each cell as well as the transport carriage of the transport system. Its purpose is the storage of the pallets that carry finished and semi-finished products as well as single components.

Figure 3 Automatic warehouse

The robot axes are driven each by a separate servo drive system which communicates and is controlled by the main PLC.

2.2.2. Linear transport system

The SUPSI learning factory transport system (Figure 4) is constituted by a linear motor equipped, at the moment, with two carriers, which can independently move in order to allow the factory operations:

- The first carrier positions the SCARA robot along the line allowing it to serve all the different stations;
- The second carrier has the purpose of transporting pallets to and from the warehouse. Both the SCARA robot and the Cartesian robot in the warehouse are able to load and unload pallets from this carrier.

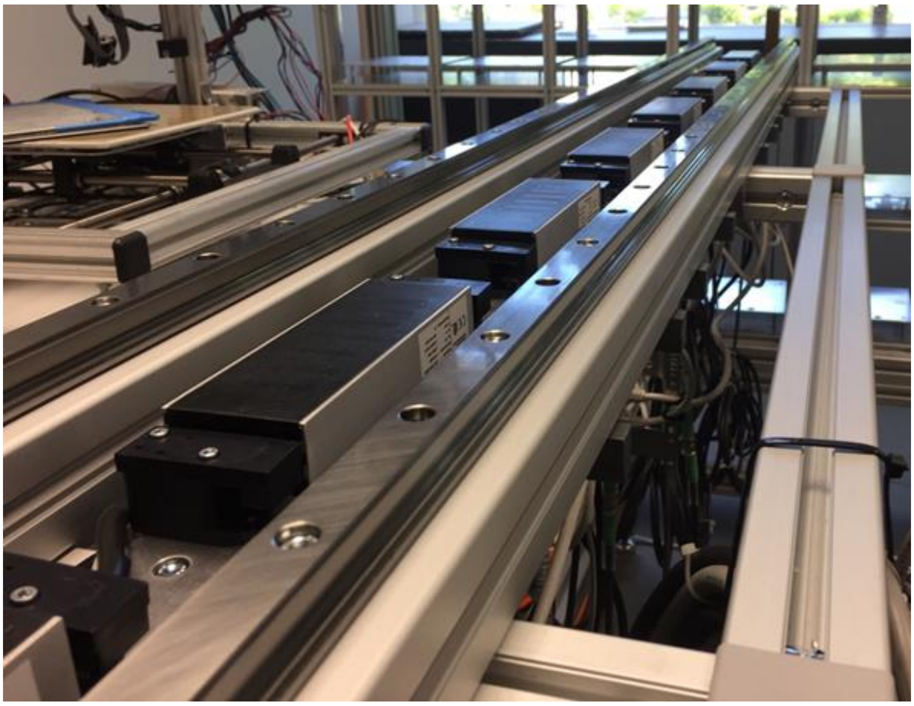


Figure 4 Linear transport system

This technology applied to transport systems is a very recent advancement in the state of the art and very few installations can be found around the world at the moment.

Specifically, the installed system is the “LMS” from Rexroth, a new, unique technical solution for transporting and positioning materials and workpieces. It can perform in many situations where traditional rollers, chains or belt systems reach their limits. It delivers higher accuracy, allows for freely program individual and synchronized movements, and is faster than traditional systems.

The main advantages of this technology are:

- All carriages can move independently from one another
- Carriages are totally passive and thus they do not require any cable connection
- Fast and precise: high throughput, high position repeatability
- Easily integrated: freely configurable track layout, saves space and costs
- Flexible: scalable carrier size/weight (1 kg to 1,000 kg),
- Cost-efficient: transport system can act as handling axis for easier handling
- Autonomous: perfect for i4.0 solutions, for more flexible production

Key technical data:

- Wide performance range from 60 N to 3,000 N
- Speeds of up to 5 m/sec
- Positioning accuracy of up to 10 µm
- Magnetic disks standard or vacuum-compatible up to 10-8 mbar
- Temperature range up to 150 °C

2.2.3. PLC and HMI cabinet

This module (Figure 5) is the control node of the factory, containing the two PLCs which orchestrate all the different components of the factory, the SCARA robot controller, digital and analog I/O modules and an HMI which allows to perform manual operations, start automatic routines and monitor a wide set of parameters.

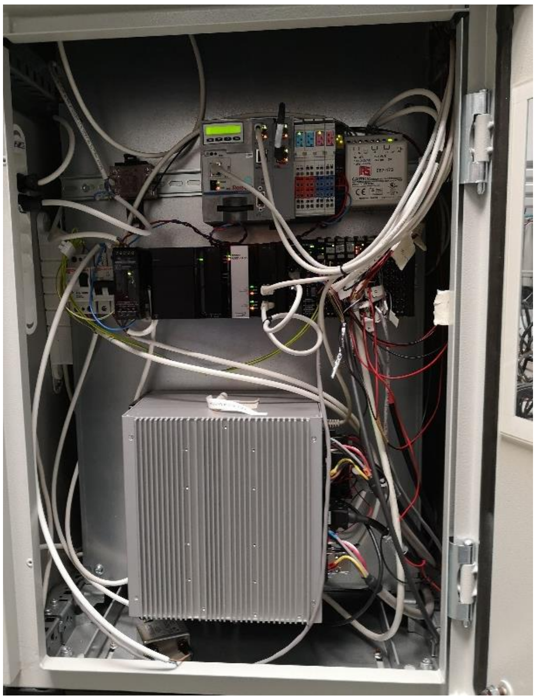


Figure 5 PLC and HMI cabinet

The main devices installed in this cabinet are:

- **The master PLC:** Omron NJ501-1400, an advanced controller allowing for basic ladder programming, structured text programming, network setup (Ethernet/IP and EtherCAT) and it also as a built-in motion control feature which allows to perform part of the control of servo drives directly in the PLC.

Furthermore, this model has a built-in OPC UA server, one of the pillars of industry 4.0, which allows to easily expose PLC variables to the outside world, a feature which is crucial for the development of the digital twin (2.3) and which allowed for a much easier interface with the installed SCADA software (3.4).

- **HMI** (Figure 6): Omron na5, which is a completely programmable terminal able to interact directly with any PLC variable, allowing to monitor and command any implemented routine or feature in the SUPSI learning factory.

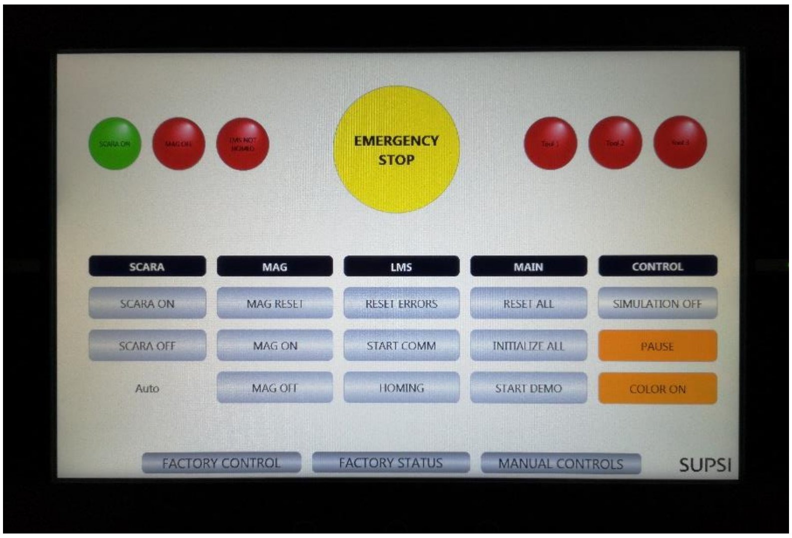


Figure 6 HMI interface example

- **A communication coupler:** Omron ECC203, connected with several digital and analog I/O units. This unit is connected to the main PLC via EtherCAT allowing for a very fast communication.
- **The slave PLC:** Rexroth IndraControl L45, which has the sole purpose of interacting with the transport system (2.2.2). This solution has been implemented due to the complexity of such a system, in fact, for the

moment, the libraries that allow to control the transport system are not available for third parties PLCs, and thus the effort of re-writing these libraries for the master PLC would have been much more expensive than to install a second, dedicated PLC.

- **The SCARA robot controller:** Omron R6Y-YRC, which directly controls the robot behaviour following the commands coming from the master PLC.

2.2.4. Grippers warehouse

This station (Figure 7) stores the different grippers needed for the robot to perform its routines. At the moment there are 3 grippers available: 2 suction cups and a fork; the former are utilized for interacting with the work pieces while the latter directly with pallets and printing beds. The current warehouse is static but there is an actuated version under development (see section 3.3).

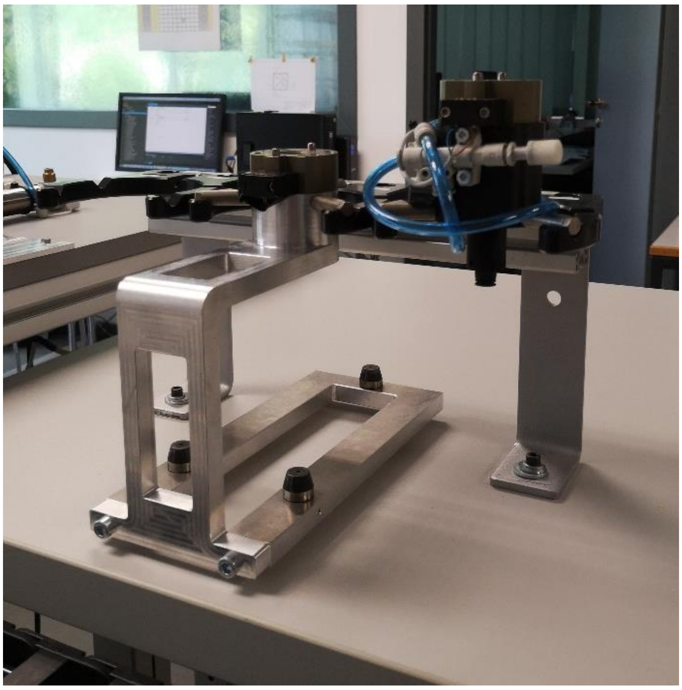


Figure 7 Grippers warehouse

The gripper changing process relies on a quick-change system by Schunk (Figure 8), which consists of a passive interface installed on each gripper and of a pneumatic system installed on the robot end-effector. The pneumatic system has six electrovalves built-in, of which two are used to activate the gripper hold/release mechanism and the remaining four to regulate just as many fluxes of air going to the gripper itself, allowing the use of pneumatics. Furthermore there is a connector between the two parts which allows to use electric grippers or to install sensors or accessories.

In the current state, the two suction cups are activated by one of the built-in electrovalves and the vacuum generator is equipped with a sensor that allows to detect whether the suction cup is holding or not the workpiece.

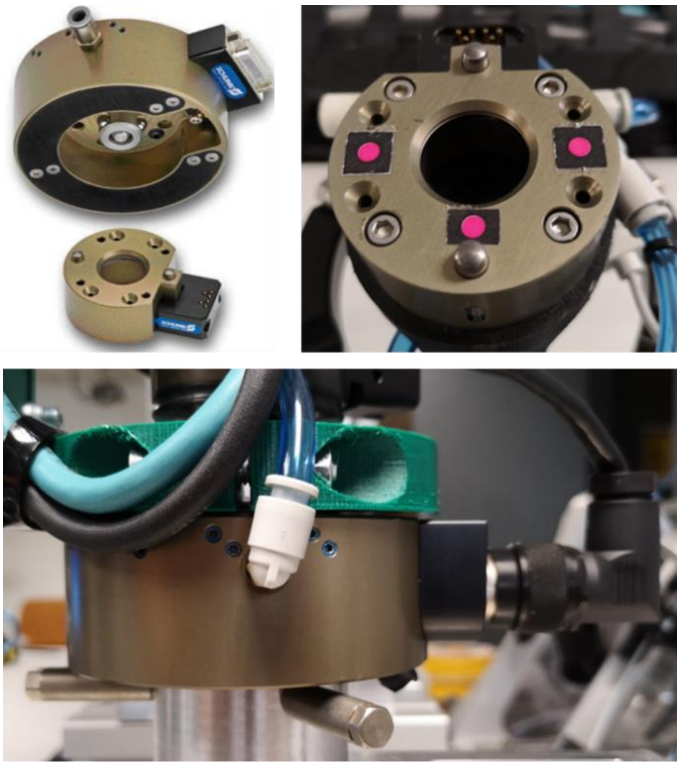


Figure 8 Quick change system

2.2.5. Production modules

The production modules selected for the pilot production are 3D printers (Figure 9 and Figure 10) which needed to be inexpensive, especially to operate, and thus a professional model was not a feasible alternative. This led to the choice of an hobbyist model which has the following characteristics:

- Ethernet communication, which, after a dedicated script was developed for this purpose, allows the PLC to send commands to the machine.
- Interchangeable toolheads: single and double filament extruders, milling head and laser source.
- A mechanical interface which allows for the interaction with the robot.

Specifically the selected machines are ZMORPH 2.0 SX, which met all the requirements above.

A dedicated code in the PLC allows sending commands to the machines, for example to start a certain print or to pre-heat the extruder.

Figure 9 Production unit: 3D printer

Figure 10 Production unit: Laser engraver

The SUPSI learning factory has been designed in order to be modular and reconfigurable, thus the production modules selected for the pilot production can be substituted with completely different machines depending on the specific need; for example in the project QU4LITY (see section 4.2) they will be substituted with testing machines for bearings and small shafts.

2.2.6. Automatic detachment station

This station (Figure 11) has been developed specifically for the SUPSI learning factory with the purpose of allowing the automatic detachment of the printed items from the printing bed itself. In fact, there are not any systems with this purpose sold on the market and many research activities on this topic are being carried on.

The system presented in this paragraph was completely developed in-house, and has the dual aim of detaching in automatic the workpiece that has been printed and, at the same time, to not lose the position of or flip the workpiece itself in order for the robot to be able to pick it up afterwards.

Figure 11 Automatic detachment station

The detachment process can be summarized as follows:

- The 3D printer manufactures the required workpiece on an especially designed printing bed substituting the machine's original bed, which allows printing on a deformable rubber membrane.
- After the print has been completed, the printing bed is taken out of the machine by the SCARA robot and loaded on a dedicated bay on the detachment station.
- A set of four pneumatic pistons lock the printing bed in position.
- A linear electric actuator placed below the printing bed rises until it gets in contact with the rubber below the printed workpiece whilst the SCARA robot grips with a vacuum cup the workpiece upper surface.
- The linear actuator rises, deforming the rubber membrane synchronized with the robot.
- The deformation of the rubber causes the workpiece to be detached and the robot, which is already holding the workpiece, can carry it to storage.

2.2.7. SCARA robot

The SCARA robot (Omron R6YXGL400150, Figure 12) is mounted on one of the linear transport system carriages allowing it to serve all the different stations. The robot performs the assembly operations and it is responsible for loading and unloading the production modules as well as the automatic detachment station.

The robot has been equipped with a safety pneumatic device mounted on the robot end-effector dedicated to collision and overload protection with automatic reset against damage resulting from collisions or overload conditions.

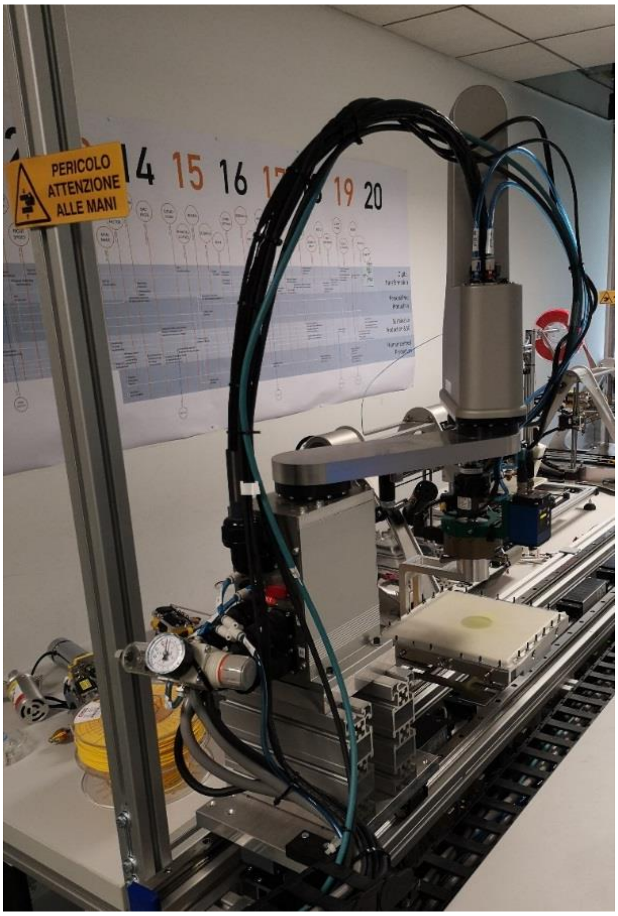


Figure 12 SCARA robot

2.2.8. Machine vision

The robot toolhead has been equipped with a smart camera (Wenglor B50S103 Figure 13), this allows to avoid mechanical jigs and to make the whole system more elastic and robust in general.

The camera has been programmed in order to:

- Recognize the tan shapes and measure the position of their centre of gravity and their rotation with respect to the camera reference frame. This allows to guide the robot path and to grip the tans regardless of their position on the transport pallet or on the printing bed (for the detachment operations).

- Recognize markers attached to the quick change system interface mounted on the grippers. This allows to measure the gripper position and guide the robot when it needs to collect it.

Figure 13 Smart camera

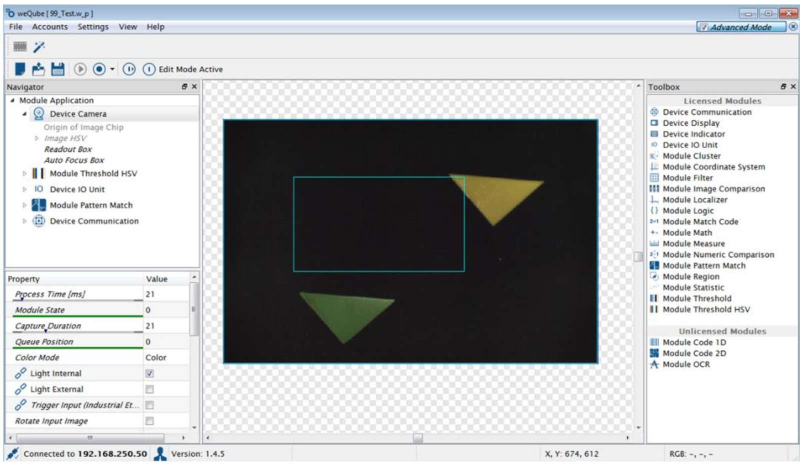


Figure 14 Smart camera software interface

In order to perform these operations and transfer the measured coordinates into the robot reference frame, a dedicated calibration routine has been developed. In short: the robot its manually positioned on several identifiable targets and the position and orientation of these same targets are then measured with the camera; by confronting the results it is possible to calculate the transformation matrixes between the two systems, which need to comprehend: translation matrix, rotation matrix and conversion from pixels to mm.

2.2.9. Quality inspection station

This station can inspect all the workpieces going through the linear transport system and it is enabled by a 2D laser triangulation scanner (Figure 15) which, coupled with the motion on the transport system and an embedded linear encoder, allows to obtain a very precise 3D point cloud of the workpiece. This allows for dimensional analysis, presence check, bar code reading and writing/figure check.

Figure 15 Laser scanner

2.2.10. Additional PLC stations

In addition to the learning factory basic layout there are two additional PLC stations dedicated to the educational purposes of the factory. This solution allows to teach and practise to three different groups of students in parallel at the same time. This is possible thanks to the digital twin of the SUPSI learning factory (see section 2.3), which allows to program the PLC and see the results on an exact simulated replica of the SUPSI learning factory. These stations are equipped with the same master PLC that controls the factory and, thus, can be programmed exactly in the same way.

2.3. Digital twin

A digital twin is a digital replica of a living or non-living physical entity [27]. The Digital Twin is a cornerstone for optimization, simulation, analytics and monitoring, that are key strategic activities for manufacturing companies in order to empower efficient configuration and use of production resources. The SUPSI learning factory encompasses an evolving digital profile, based on constant and efficient digital-real synchronization through IoT devices.

The Digital Twin is based on massive, cumulative, real-time, real-world data: these data create an evolving profile of the pilot factory process in the digital world, and provide important insights on system performance, leading to actions in the physical world.

The SUPSI learning factory digital twin will represent the key enabling technology for the following implementations:

- **Virtual commissioning:** to configure and test beforehand the system future state and implement the control logics. This feature is particularly significant for the educational purposes as well, in fact, it allows students to program different PLCs in parallel and to test the developed routines on a realistic model free of the risk of damaging parts of the actual plants or of getting hurt.

- **Multidisciplinary simulation:** to reproduce the system behaviour in the digital world, to support system performances analysis and what-if scenarios.
- **Automatic data aggregation:** the system will be able to automatically generate reports summarizing and highlighting the parameters of interest.

The complete digital twin of the SUPSI learning factory is still under development and it is foreseen that its expansion in terms of accuracy and features will be constantly under development. Nevertheless some functions are already in place and in the following paragraphs a short description is presented.

2.3.1. Functional digital replica

The first version of the functional digital replica of the SUPSI learning factory is already in place and it allows for:

- Accurate reproduction of the factory behaviour in parallel with the actual operations being performed
- Accurate reproduction of the factory behaviour offline, allowing to test the implemented code written in the PLC controller in a simulated and, thus, safe environment. This feature is particularly useful for the educational purposes:
    - Students working on the master PLC (2.2.3) can program and test their code with no risk of collisions or, in general, creating any damage.

- Students working on the additional PLC stations (2.2.10) can work in parallel, without the need of taking turns on the actual plant with the other groups.

Furthermore, these functionalities will be at the basis of the agent-based scheduling algorithms being developed to optimize the manufacturing process and the use of the resources (see section 5.3). This will allow to optimize processes based on the resources available and on the objective being imposed by the priority in the orders queue.

The functional digital replica is being completely developed in-house, thanks to the long and extensive experience in this field that SUPSI has gained over the years.

The software used comes from TTS (technology transfer system, www.ttsnetwork.net) which is a partner company specialized in this field and developing its own software.

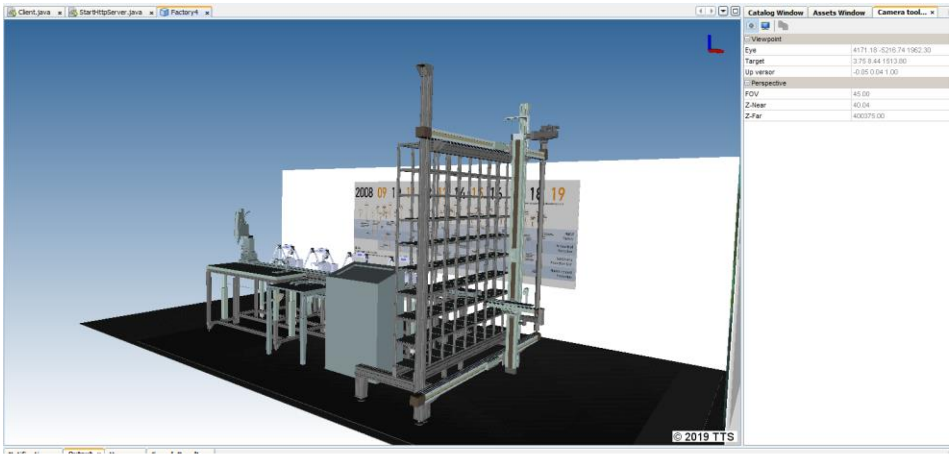


Figure 16 functional digital replica programming environment

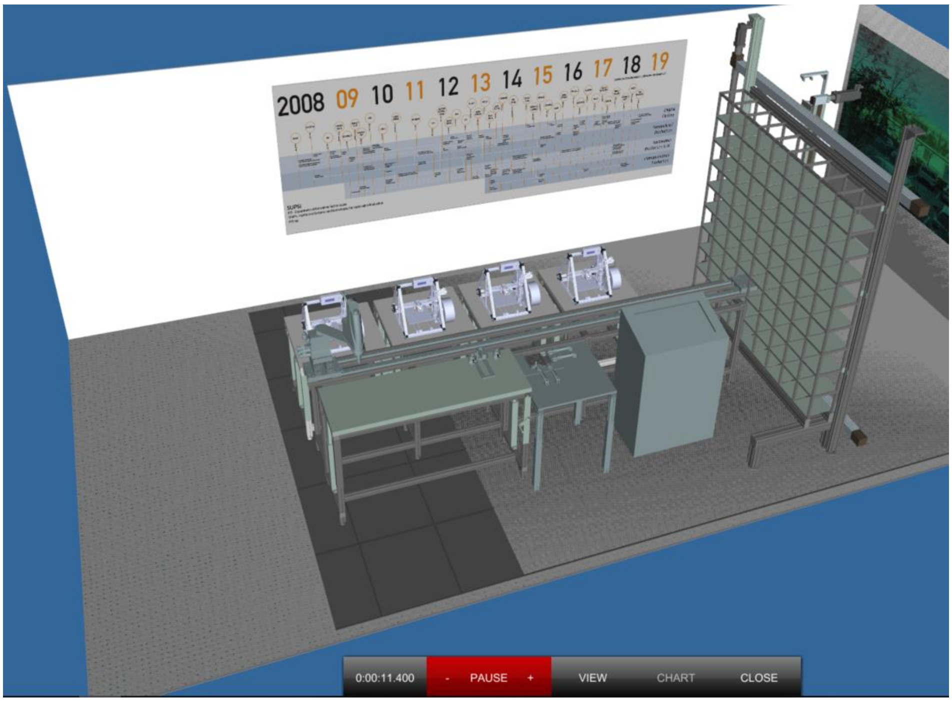


Figure 17 Example of the functional digital replica

2.3.2. Data monitoring

Data monitoring, comprehensive of a dedicated interface, is another feature being implemented in the SUPSI learning factory. This tool is capable to interact with the PLC controllers and with numerous sensors installed on the factory modules and extract, store and elaborate the data of interest in each single case.

The first version being currently developed and used is dedicated to energy consumption (see example in Figure 18). This type of data analysis is performed together with the SUPSI research group dealing with sustainability.

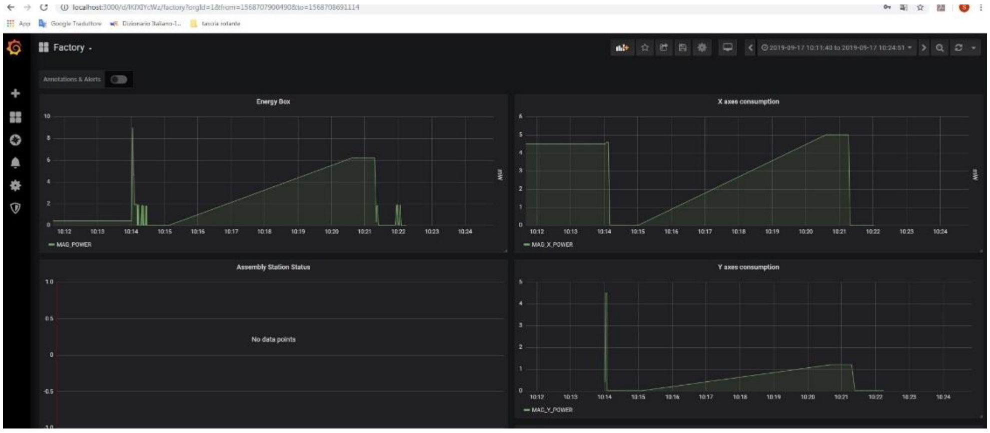


Figure 18 Data monitoring example

The idea is to insert the consumption parameters in the objective functions tuning machine and scheduling operations, in order to be able to find approaches that minimize it.

2.4. Pilot production: Tangram

For the purpose of implementing a demo version of the learning factory, and especially with the educational purposes in mind, a pilot product with the following characteristics needed to be selected:

- A sufficient complexity level for the management engineering purposes
- Large palette of possible customizations
- Possibility to combine internal and external flows of components/material
- Manufacturing processes compatible with a non-industrial grade environment
- Nor or very little production of by-products/waste
- Low production cost
- Possibility to use the final product as a gadget to give visitors during events

The selected product is a Tangram game-set and the relative box to pack it. Tangram is a Chinese puzzle game for little kids composed by seven geometrical pieces (named "tan"):

- 2 large right-angle triangles
- 1 medium right-angle triangle
- 2 small right-angle triangles
- 1 square
- 1 parallelogram

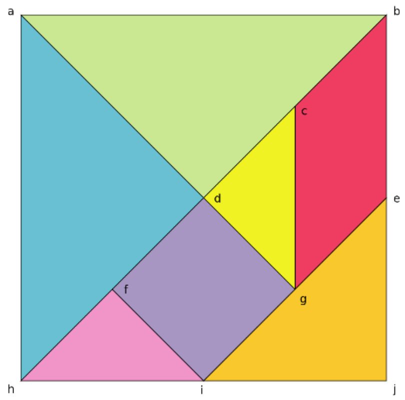


Figure 19 Basic Tangram gameset layout

The main scope of the puzzle is to picture a certain figure (Figure 20) without superimposing any of the tans.

The tans composing the game are produced inside the factory using additive manufacturing and are the packaged either inside plastic boxes, which are produced in the factory through additive manufacturing as well, or wooden boxes, which are purchased in a woodworking shop nearby.

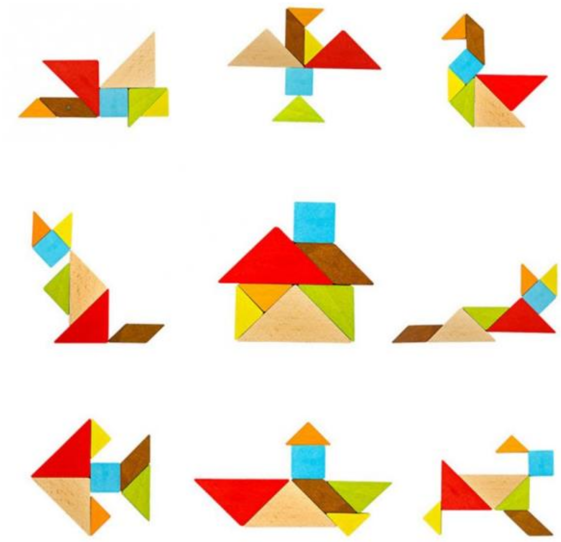


Figure 20 Examples of figures representable with a Tangram game-set

This product fits perfectly with all the requirements imposed, in fact:

- It allows both for components produced in-house and for components bought from third suppliers, and thus to mix internal and external logistic fluxes.
- It is highly customizable (Figure 20):
    - Each tan of a game-set can be of a different colour.
    - Each game-set can be packed in either a wooden or plastic box.
    - The colour of each plastic box and relative lid can be chosen.
    - The lid of each wooden box can be personalized via laser engraving.
- Assembly operations, production and logistics are involved in the management of the learning factory.
- Additive technology based production and wood laser engraving do not require an industrial grade environment and do not have any significant by-product.

- the production costs are very low both regarding the raw materials costs and the maintenance of the machines.

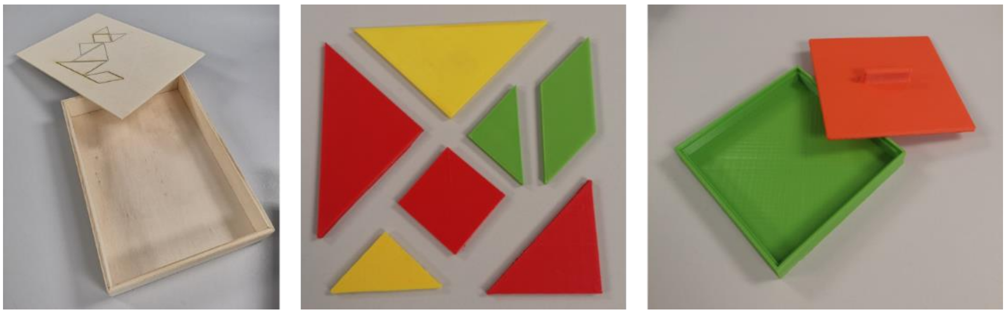


Figure 21 Tangram game-set and possible boxes

Furthermore, this product poses very well as a marketing tool, it is, in fact, possible use it as a gadget to give to visitors as a gift, with the further possibility of allowing these visitors to personalize their own set.

3. Education

As already stated in section 1.1, education is one of the main drivers for the development of the SUPSI learning factory. The main idea is to give students the opportunity of a real hands-on education by challenging them with real-world problems on an actual plant, with a particular focus on the industry 4.0 paradigm. This represents both an opportunity to fill a gap in the management engineering curricula, which historically lacks of laboratories, and to meet the needs of the companies that will hire them in the future. In fact, as argued in [28], nowadays, there are plenty of studies that seek to determine which are the skills that should be met by an engineer. Communication and teamwork are some of the most recurrent ones associated with a knowledge of the engineering sciences. However, their application is not straightforward, due to the lack of educational approaches that contributes to develop experience-based knowledge. Learning Factories have shown to be effective for developing theoretical and practical knowledge in a real production environment.

For our university the goal is the same, in other words to better our educational portfolio and enhance the quality of the engineers that we train. The main fields that we decided to address are:

- PLC programming
- Plant supervision
- Mechatronics
- IoT
- Scheduling
- 3D printing
- Vision systems

In the following paragraphs a brief introduction on some examples of the educational activities being performed in the SUPSI learning factory is presented.

3.1. PLC programming

The curricula of SUPSI course in management engineering has always comprehended a module where the basics of PLC programming were taught. The practical part of these classes took place in a computer classroom where the students completed a series of exercises throughout the semester using a PLC simulation software. After the introduction of the learning factory this approach was maintained only for the first few lessons in order to learn the basics of PLC programming. After that, the students have the opportunity of programming on the learning factory PLCs (1 group on the main PLC controlling the factory and two groups on the dedicated additional PLC stations(see section 2.2.10)) allowing them to experience on the field problems and see the actual results of what they are programming in motion.

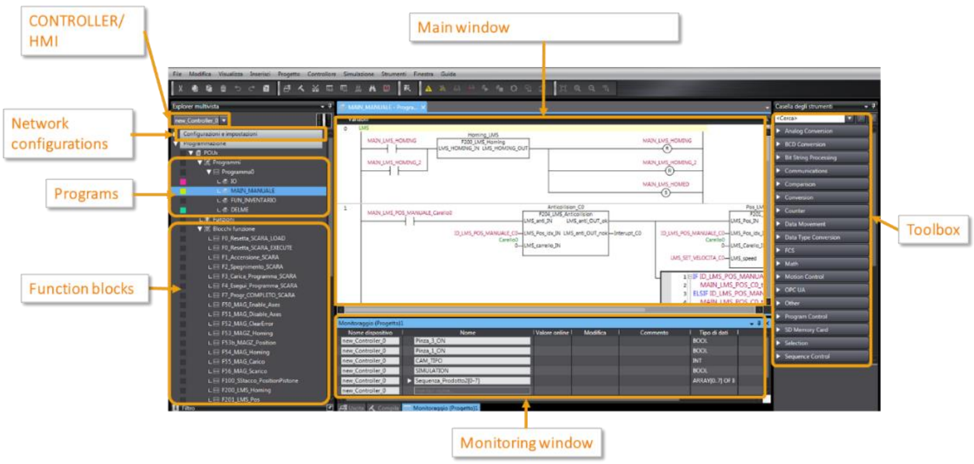


Figure 22 SysmacStudio main interface window

The PLCs that the students work on are of the NJ family of Omron, specifically 1 NJ301-1100, 1 NJ301-1200 and 1 NJ501-1400. The software used to program the controllers is SysmacStudio of Omron (Figure 22), which allows to program both with ladder language and ST (structured text) combined. It also allows to configure the factory network, manage I/Os, monitor varibles, write function blocks, program the HMI and to tune and control servo systems.

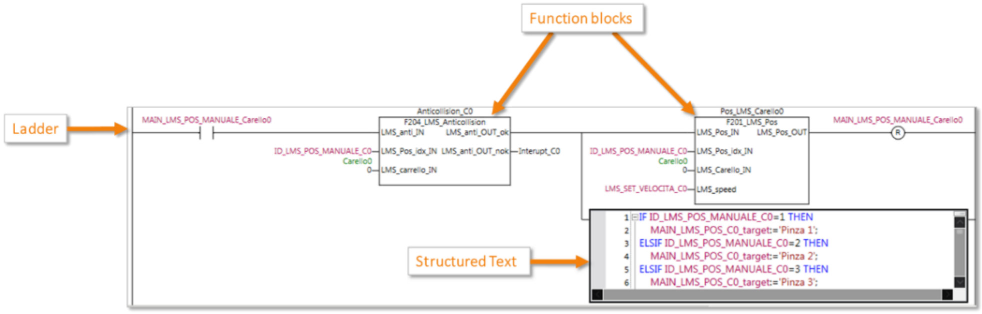


Figure 23 Programming example

There are many type of exercise that can be performed with this setup:

- Basic programming of simple contacts
- Advanced programming with function blocks
- Programming of the behaviour of a single module of the factory
- Programming of routines involving more modules
- Optimization of existing routines
- Network configuration
- I/O configuration

Furthermore, students learn how to map cables and tubing, being asked to document these networks.

3.2. IoT

The SUPSI learning factory is the perfect test bed to install e develop IoT applications, being completely open and accessible. Several experiences with groups of students have already been carried on, both during the regular lessons and in dedicated extra-curricular activities.

In the following sections a few examples of educational activities in this area are presented.

3.2.1. IoT Devices

This example is related to the course of "Industry 4.0 e la fabbrica del futuro 1" (Industry 4.0 and the factory of the future) part of the curriculum of SUPSI master studies in management engineering.

The objectives of this course are:

- To learn and use the Rasperry PI platform for data acquisition, elaboration and communication.
- To analyse the acquired data by means of statistical and data mining approaches.
- To define and design the software and hardware infrastructure necessary for the data acquisition:
    - Selection of the correct sensors.
    - Installation of these sensors.
    - Design of the data model.

Students have the chance to learn and put into practice the most diffused technologies for this purposes in the industrial automation world.

Students work divided in groups which design and build a prototype of a system, complete of both hardware and software, and install it and test it on the SUPSI learning factory.

In Figure 24 there is an example of the work, where a group of students designed and tested an RFID system with the aim of tracking and checking the pallets contents.

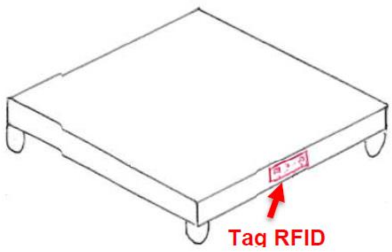
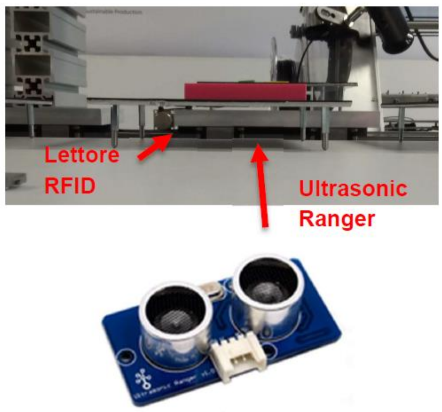
Controllo postazioni di lavoro	
Posizione Tag RFID	**Posizione lettore RFID e Ultrasonic Ranger**
	

Figure 24 Example of student project

The scope of the system was to avoid the use of the wrong pallet for a certain operation; which could happen due to a misplacement in warehouse or failing to update the inventory when manually loading or unloading components, for example wooden boxes or lids.

3.2.2. Life Cycle Inventory data

This example is related to the course of "Design, monitoring and management of industrial plants" part of the curriculum of SUPSI master studies in management engineering.

Within this course, groups of students are assigned projects aiming at identifying the sensors needed in order to retrieve Life Cycle Inventory data during the learning factory operations and then to develop and install those systems. LCI information collection will allow to calculate the environmental impacts of the processes carried out in the mini-Factory through Life Cycle Assessment methodology.

An example of final poster produced by the students can be seen in Figure 25, in this particular case the students were asked to develop and test a weighing station capable of measuring the printed TANGRAM tans given the following requirements:

- The system must measure the piece's weight with a measurement range between 1 and 40g
- The system must have a sensitivity of 1 g
- The system must be able to obtain the weight of the piece in maximum 30 seconds
- The system must be able to handle a piece with a maximum area of 8x8 cm
- The system must be able to interact with the PLC currently in use by displaying the values on the screen and saving them in a database
- The pieces are placed on the weighing system by the robot.
- The weighing system must not interfere with the robot's standard movements but must be positioned in the working area of the same.

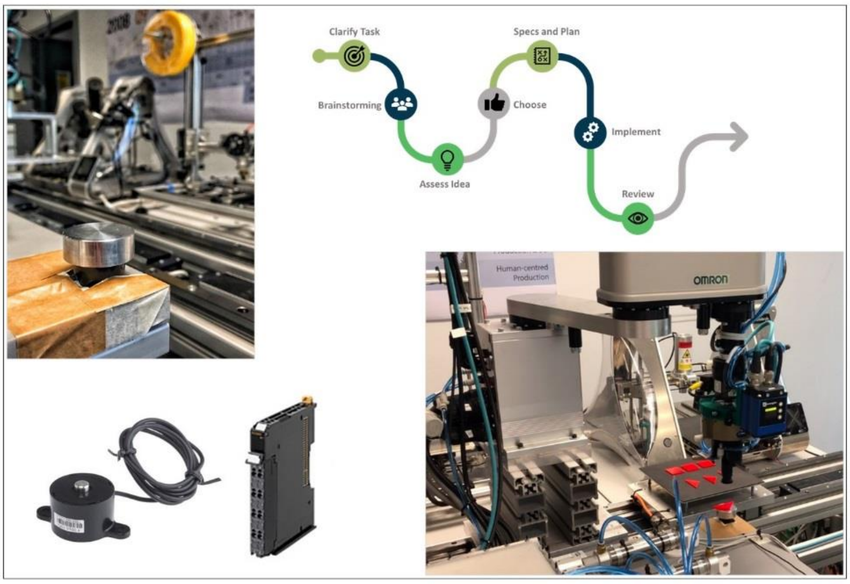
Students designed, installed and tested the system within the activities performed in the semester.

Scuola universitaria professionale della Svizzera italiana
Dipartimento tecnologie innovative

SUPSI

Load Cell for Life Cycle Inventory of the Mini-Factory

Students		Professor	Customer
Eleonora Biscotto	Alessandra Leone	Marco Silvestri	ISTePS Mini-Factory
Deborah Leone	Andrea Monti		
Course	**Module**	**Academical Semester**	**Date**
Master of Science	MPC_DMMIP	Spring 2019	27th June 2019



STUDENTSUPSI

Abstract

The project aims at identifying the sensors needed in order to retrieve Life Cycle Inventory data during the mini-Factory functioning.
First of all, the AS-IS analysis has been conducted in order to understand the existing equipment. This analysis has been done with the tool of UML diagrams. This is a crucial first step to design and implement changes. After that, a specific use case has been chosen; the use case of this project is "production of one complete tangram kit". Subsequently, the Low Hanging Fruit approach has been used to select the project to be implemented. This approach helps to choose the project that is supposed to have the bigger impact with the less possible effort. After having applied this approach, it has been chosen to implement the weighing process with the final aim to understand the quantity of plastic wasted or scrapped during the mini-factory functioning. A state of art analysis has been later conducted and the user requirements have been collected. For each requirement, a test plan has been also defined. Later, the practical implementation phase has started. The load cell and a I/O analog convertitor have been purchased and integrated in the mini-factory equipment. In addition, code functions for the scara robot and for the weighing process have been programmed in the PLC. Finally, a practical demonstration has been prepared and a plan for the remaining activities has been proposed.

Objective

The project aims at identifying the sensors needed in order to retrieve Life Cycle Inventory data during the mini-Factory functioning. LCI information collection will allow to calculate the environmental impacts of the processes carried out in the mini-Factory through Life Cycle Assessment methodology. Project activities are focused in the identification of the appropriate sensors that could enable the gathering of this data. Already existent sensing technologies or other possible sources (e.g. PLCs, SCADA…) should be taken in consideration and properly integrated.
In this specific project, load cell sensor has been implemented in order to monitor the plastic usage and calculate plastic waste.

Conclusion

A commissioning process (see the V-shaped model illustrated in the figure below) has been adopted for verifying and documenting that the performance of the system meets the defined user requirements. The system is correctly integrated into the existing architecture and is able to meet the quantitative requirements of the weighing process. Indeed, it is able to interact with the PLC currently in use by displaying the weight's values on the screen and saving them in a database without interfering with the other equipment that are present in the mini-Factory.

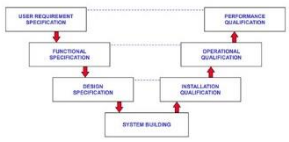


Figure 25 Example of lab activity performed by students

3.2.3. Summer school on the internet of things 2018

The Institute for Information Systems and Networking (ISIN) of the Department of Innovative Technologies (DTI) of the University of Applied Sciences of Southern Switzerland (SUPSI) organizes this Summer School on the Internet of Things.
The general educational objectives of the summer school are:

- To understand the IoT world: the technologies, application contexts, development strategies, implementation problems, and the possible solutions.
- To gain a detailed knowledge of the key technologies and the specifics of the key application domains.
- To learn how to plan and implement real-world applications that involve heterogeneous devices using various middleware layers and user interfaces.

At the end of the summer school, the students will have gained a fundamental understanding of the key IoT platforms and devices that can be used for development purposes and will be able to create solutions and develop software for various purposes.

In the 2018 edition the students worked on several prototypes of IoT applications and installed them in the SUPSI learning factory.

To give an example, one of the groups developed an application running on a smartphone that, using the embedded camera, monitored the consumption of the PLA filament on one of the production 3D printers (section 2.2.5).

3.3. Axis design, development and control

The design, development and control of an axis is a topic studied in many different engineering curses and, typically, is a completely theoretical process. In the SUPSI learning factory it is possible to perform a practical exercise of this whole process. In addition, the PLC controllers installed feature an additional “motion” module, which allows to perform most of the control setup inside the programming environment of the plc itself.

A practical example of what can be carried out is the laboratory activity being performed in this moment, which requires the students to design and tune a new rotating table with the function of serving as an automated gripper warehouse for the SCARA robot, substituting the present static one.

Synthetically, the students will:

- Dimension the size of the table starting from given requirements.
- Dimension the servo drive and relative reducer given the required law of motion and the calculated loads.
- Find the right motor-reducer-drive by selecting from a catalogue based on the previously calculated data.
- Interface the drive with the PLC.
- Tune the control of the system.
- Program the PLC in order to be able to use the rotating table in the factory operations.

Figure 26 CAD model of the rotating table for warehousing the robot grippers

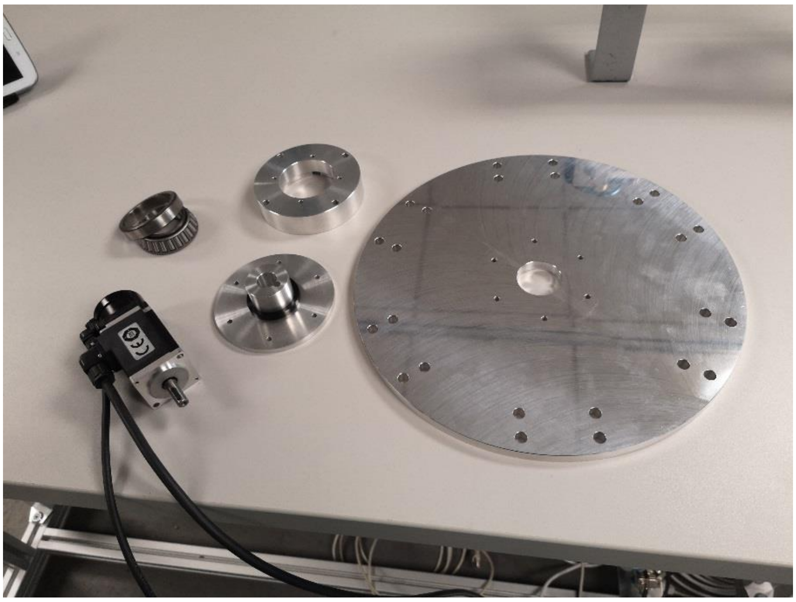


Figure 27 Basic components of the rotating table

The table is being manufactured in this moment and will be ready shortly.

3.4. Supervision

The SUPSI learning factory is equipped with a SCADA software, specifically GE ifix, which allows to monitor the activity and to interact with certain features of the factory. In this case also, the curricula of SUPSI course in management engineering has always comprehended a module where the basics of SCADA programming were taught. The practical part of these classes took place in a computer classroom where the students completed a series of exercises throughout the semester on a SCADA software fed with simulated data. After the introduction of the learning factory, it then became possible to let the students work on a SCARA interfaced with an actual, working plant.

The students start by learning the basics of the software and then experience hands on the interface and programming on real-world and synchronized data.

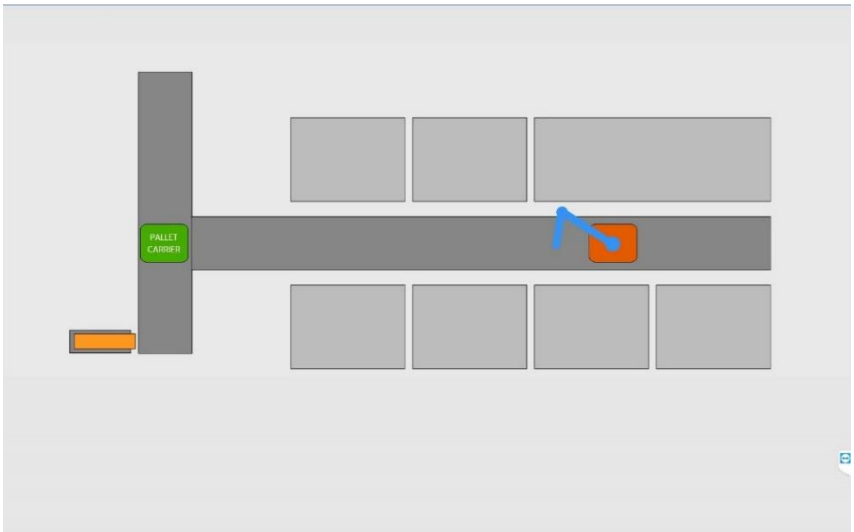


Figure 28 Basic representation of the SUPSI learning factory seen by the SCADA software

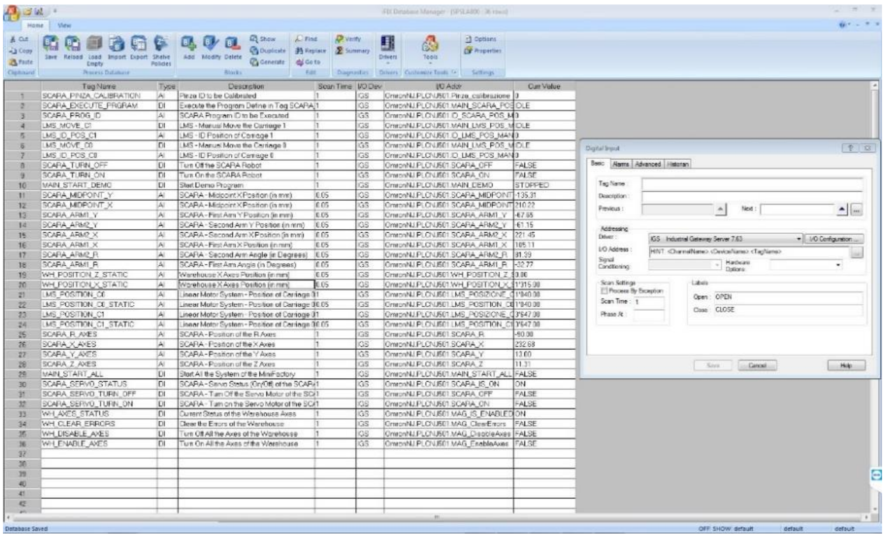


Figure 29 Example of a SCADAdatabase in the SUPSI learning factory

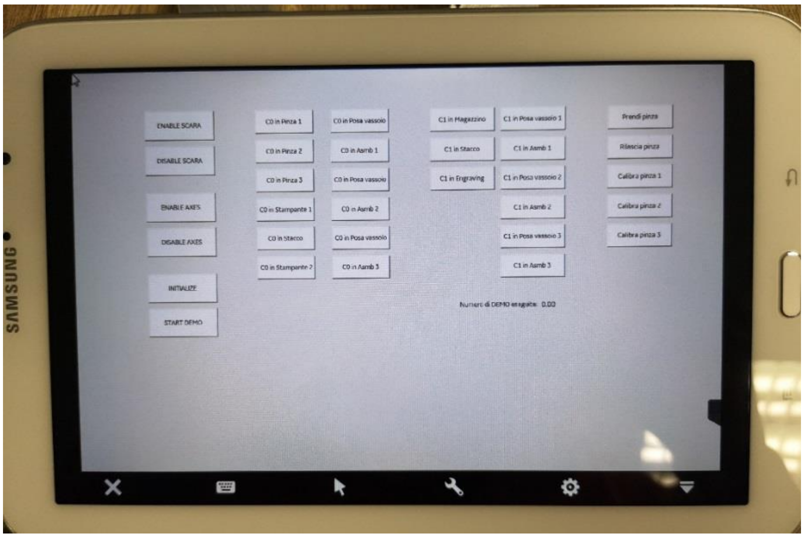


Figure 30 Tablet interface example

Furthermore, through a remote desktop control application, it is possible to monitor and interact with the factory via a tablet or laptop through the internet. In the example shown in Figure 30 it is possible to control basic operations of single modules of the factory; for example sending one of the carriages of the transport system in a certain position or running a certain program on the SCARA robot.

The SCADA installation is very recent and under development.

4. Research projects

4.1. Concept

As introduced in section 1.1, two of the main purposes of the SUPSI learning factory are to function as a test bed for research projects and to facilitate the technology transfer between the academia and industry. The learning factory fills a big gap regarding these two activities allowing for a realistic environment that is a perfect ecosystem to test and develop new solutions regarding many different aspects of a manufacturing plant. In an actual functioning plant it is, in fact, very difficult to operate since it is very complicated and costly to stop the production and this problem affects greatly the outcome and effectiveness of a research project that often needs multiple test campaigns and a quite high level of integration with the machines and management software.

In the SUPSI learning factory there are many active projects, in the following sections the concepts of the main ones are described.

4.2. QU4LITY

QU4LITY is a project funded under the "Manufacturing technologies" impulse programme by Innosuisse (Swiss innovation agency). This program funds innovation projects at the interface between research and technology transfers that Swiss companies conduct together with research institutions in the digitally-oriented "Industry 4.0 and Modern manufacturing technologies" segment.

SUPSI leads this project and has drafted it and is carrying it out together with:

- INTERROLL SA: a world-renowned manufacturer of roller conveyors/storage systems. Headquartered in Switzerland, has a global network of 32 companies with turnover of around CHF 450.7 million and 2,100 employees (2017).

- HAMMERLE SA: a Swiss system integrator specialized into inspection, marking and special machines manufacturing. In the value chain addressed by QU4LITY, HAMMERLE plays the role of the first system integrator, interested in including the QU4LITY testing cells in their existing portfolio of solutions.
- HSLU (Hochschule Luzern): The university of applied sciences of Luzern.

The project has the goal of developing a smart, fully automated and modular cell for quality control, empowered by a pervasive use of key digital technologies towards Industry 4.0 paradigm implementation. QU4LITY targets an industrial scenario where smart automation for quality-testing establishes a competitive advantage over existing solutions: the quality control for bearings and shafts. Those components (EU annual production of 8.2 bln) are of remarkable importance and their correct behaviour is often critical for the performances of the systems in which they are installed; thus, integrators implement control procedures, in order to verify the compliance with required standards. These procedures are nowadays mostly manual, limiting the number of tests and requiring the constant presence of operators for data analysis.

In this case, the SUPSI learning factory will function as the test-bed of the project, QU4LITY has a threefold objective as per the figure below:

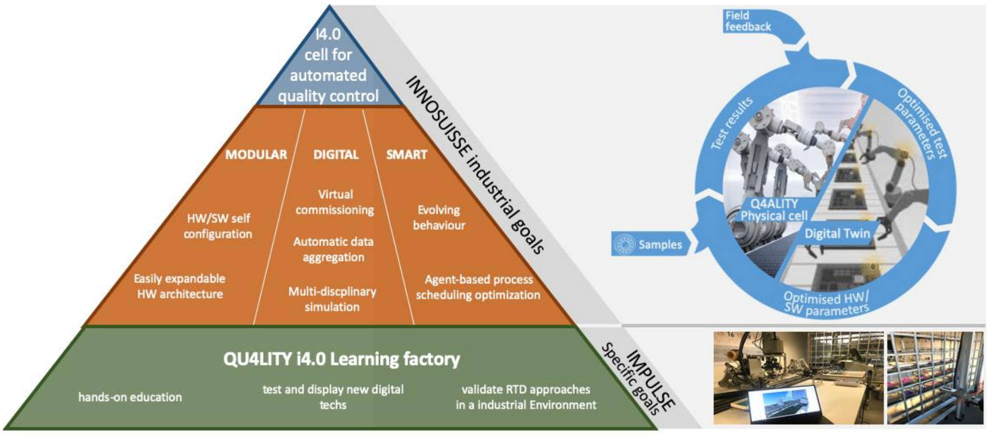


Figure 31 QU4LITY framework

- **Level 1 - To deploy an I4.0 quality-testing cell:** to increase throughput rate (+60%); to reduce testing unitary cost (-50%); to automatically generate quality assessment report; to increase quality compliance (+60%);
- **Level 2 - To investigate Modularity, Smartness and Digitalization** as drivers to substantiate the I4.0 implementation, towards the integration of different modules with reduced setup times (-30%), for the implementation of processes, whose optimization is empowered by data analytics.
- **Level 3 - To promote an open-access pilot line** to demonstrate the full advantage of digital technologies and modular automation, accessible by students and companies. QU4LITY promotes Switzerland’s excellence in application of digital-based automation for manufacturing.

QU4LITY proposes a completely different automated system for quality control of manufacturing components, driven by I4.0 principles, and characterized by:

- a modular and flexible automation infrastructure,
- algorithms to optimize process parameters,

- automatic data handling and digital counterparts to enable simulations and what-if scenarios,
- full traceability on performed tests.

These characteristics are achieved in QU4LITY testing cell through the development of the following main characteristics of the cell: modular, digital and smart.

Modular: QU4LITY will be able to flexibly introduce heterogeneous quality control units requiring a minimized setup time. After the physical connection of a module, the system will automatically start communication, recognize presence, spatial position, characteristics and status, making it available for the task scheduler of the entire cell and enabling the interaction with the robots. This will be possible for a wide number of relevant technologies and control protocols. Within QU4LITY the following two implementation issues will play a critical role for this scope:

1. **Plug&Produce enabled for interchangeable modules:** this will be made by means of adopting FIWARE open implementation to regulate data exchange within the peer-to-peer information network. The proposed approach will allow at the same time an easy interfacing with shop-floor IoT and with legacy automation and data management.
2. **Vision-based flexible handling:** the system will be able to process a relatively wide set of bearings and shafts without the need of manual external inputs. This will be achieved thanks to machine vision algorithms running on cameras installed on-board the robots that serve the modules.

Digital: QU4LITY testing cell will rely on optimization, simulation and monitoring tools, in order to empower efficient configuration and use of resources. In particular, the main implemented features will be:

1. **Virtual commissioning:** to configure and test before-hand the system future state and implement the control logics.
2. **Multidisciplinary simulation:** to reproduce the system behavior in the digital world, to support system performances analysis and what-if scenarios.
3. **Automatic data aggregation:** the system will be able to automatically generate reports summarizing and highlighting the parameters of interest towards a closed-loop constantly improving engine for optimized quality tests.

These will be achieved by means of developing a digital twin of the testing cell based on constant and efficient digital-real synchronization through IoT devices creating massive, cumulative, real-time, real-world data: this data creates an evolving profile of the testing cell process in the digital world, and provides important insights on system performance, leading to actions in the physical world.

Smart: the QU4LITY testing cell is conceived to operate in dynamic contexts where the family of tested components can change, and the tests' parameters can vary according to the in-operation performances. QU4LITY testing cell, thanks to its digital foundations, has a great quantity of diverse data coming from different sources, coherently aggregated and available to be analyzed by means of artificial intelligence algorithms. In particular, within QU4LITY, the following three implementation issues will play a critical role:

1. **Big data analysis:** Complex datasets involving both computer images and test measurements in structured format representing a wide range of defective and within-specification products will be constructed. A data fusion approach will be realized utilizing deep learning methods to classify samples. In a further effort the reasoning for the classification will be

extracted to be able to not only determine defective parts but also defect types and defect severity.

2. **Adaptive behavior:** the system will be able to tune a set of process parameters (i.e. testing machines parameters) based on the aforementioned analysis performed on gathered data to compensate for any detected bias. This will be realized by cascaded control loops that correct the manipulation commands of lower level controllers.
3. **Agent-based process scheduling optimization:** A further purpose of the proposed work is the ensure that the developed solutions are efficient, related to the design constraints and, thus, able to inspect as many parts as possible in a given time window. When a number of different parts need to be inspected and when a number of different testing stations are involved for the testing jobs, an efficient schedule needs to be produced by scheduling algorithms. These algorithms are widely used in the industry today but the case of reconfigurable manufacturing systems is a new paradigm and both the scheduling model formulations and the corresponding optimization solutions need to be investigated to produce real-time-feasible and highly optimal results.

4.3. Smart Twin - DIGITAL TWIN-BASED SERVICES TO SUPPORT MANUFACTURING COMPANIES

This project is also funded under the "Manufacturing technologies" impulse programme by Innosuisse (Swiss innovation agency).

SUPSI is a partner in this project and has drafted it and is carrying it out together with:

- HSLU: The university of applied sciences of Luzern, who leads the project.

- ZHAW: The university of applied sciences of Zurich.
- EPFL: The federal polytechnic school of Lausanne.
- Shiptec: One of the biggest ship manufacturers in Switzerland.
- Siemens Mobility: is a separately managed company of Siemens AG and has 4 core business units Mobility Management, dedicated to intelligent traffic systems and rail technology, railway electrification, rolling stock concentrating all the manufacture of train-sets and Customer Services for maintenance.
- SBB: Swiss Federal Railways (German: Schweizerische Bundesbahnen, SBB) is the national railway company of Switzerland.
- ProSim: is a leading European engineering software company delivering chemical process simulation software and consulting services to the energy, oil, gas, chemical, petroleum, pharmaceutical, food & beverage and other processing industries worldwide.
- Mebag: a Swiss manufacturer of metallic structures.
- Schlindler: is a manufacturer of escalators, moving walkways, and elevators worldwide, founded in Switzerland in 1874. Schindler produces, installs, maintains and modernizes elevators and escalators in many types of buildings including residential, commercial and high-rise buildings. The company is present in more than 140 countries and employs more than 58,000 persons worldwide.

The project focuses on the Digital Twin, which can be used by the manufacturers either to provide services for themselves (internal services, often efficiency-oriented) or for their customers (customer-oriented service, new customer value propositions). The business problem is how to develop, implement and use the Digital Twin to provide internal or external services. Manufacturing firms will find more effective ways to develop and use the Digital Twin to create more value.

Owners/operators will find better ways to model their operations and to support their customers in complex multi-actor systems. The firms will receive a toolbox to help them develop and describe the value of the Twins. The broad spectrum of stakeholders is provided with relevant customer value throughout the lifecycle and at many levels from the technical to the business.

The project aims to prototype Digital Twins in different systems to explore how the Digital Twins can support multifactor value co-creation and improve business outcomes over the whole asset lifecycle. The objectives are to:

- Deliver relevant service concept use cases
- Provide a foundation for simulation-based modeling across layers
- Integrate contextual information into the data model
- Test early porotypes in lab-environments
- Prototypes in 5 companies/industries
- Extract best practices to improve implementation

The Digital Twin requires new concepts/frameworks to support the multi-actor value cocreation. This requires new frameworks and methodologies to support the development and application of the Digital Twin that can connect across the different business layers (e.g., individual components to systems of factories; technology to business; along lifecycle; operational, tactical, strategic basis). The research gap is based on considering the Digital Twin to be a service agent rather than a technology.This a new approach and our pre-study (literature survey, interviews & survey with firms) and paper (submitted) confirm this gap.

The research question in this study requires framing within the context of complex systems within of the B2B(2C) environments. The second frame is the context of capital assets, products, and equipment where the design and manufacture of the equipment typically involves a complex supply chain (see figure). Often installation is separated from the final ownership of the equipment, where the MOL phase is commonly more than five times longer than the design and manufacture phase. During the MOL phases, technologies and market conditions change requiring conversions, modifications or upgrades of the asset or plant configuration. In essence, this is a complex system-of-systems composed of components, assemblies, and products. Around the framing, the research questions are:

"what services can the Digital Twin provide in complex capital asset-based systems, who can provide these services and to whom?"

"how can we best innovate so that the Digital Twins provide Smart Services along the whole life cycle, linking technical and business layers together?".

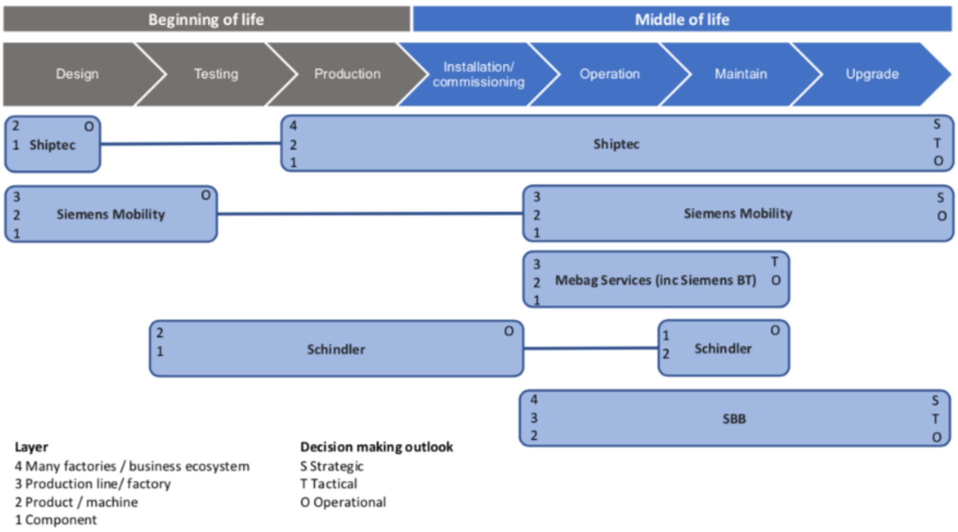


Figure 32 Smart Twin framework

SUPSI learning factory was set up to be analogous to a real factory, however here it has been so designed that it can be easily reconfigured. The factory has a Digital Twin already developed, and this is kept synchronized with the real factory. This facility will allow firms to understand what is possible and provide a lab environment to test some of their ideas before moving to a prototype in their environment.

4.4. MirrorLabs

MirrorLabs - creating similar learning environment for students all over Europe for human-robot coproduction - is a project funded under the eit (European Institute of Innovation & Technology) Manufacturing, which mission is to bring European manufacturing actors together in innovation ecosystems that add unique value to European products, processes, services – and inspire the creation of globally competitive and sustainable manufacturing.

SUPSI is a partner in this project and will carry it out together with:

- TU Delft, University of Technology ,project leader
- Laboratory for Manufacturing Systems and Automation, University of Patras
- Aalto University
- INESC-TEC Institute for Systems and Computer Engineering
- TU Braunschweig, University of Technology
- University of Tartu

Concept:

In order to educate students for "people and robots for sustainable work", students will need to access real hardware. One of the emerging Human-Robot Interaction techniques are Augmented and Virtual Reality. Combining AR/VR with existing robots infrastructure is quite challenging. Furthermore, it is even more complicated to get students familiar with all of the required background. The aim of this proposal is the development of a common, easy-to-use ICT infrastructure for the existing equipment in the labs of the participating partners. The developed software is planned to be released as open source, so that it can be used by other partners within and outside EIT Manufacturing. The project will develop a software platform and tutorials on how to set up the platform itself and how to get started to work with it.

A lot of research groups have started to investigate the role of the “operator 4.0” role within cyber physical production systems (CPPS, or HCPPS) and human robot co-production. Especially the use of Virtual and Augmented Reality within a production environment is a great opportunity for student projects – it is at the same time intuitive, motivating and creates a huge learning benefit. The generation of multiple Mixed Reality visualizations of CPPS with student projects can be both an educational but also a research benefit, if we regard the possibility to conduct user studies with the developed applications in order to deduct more general principles for human-machine interaction within industry 4.0. As numerous research institutions currently have a similar set of hardware (for example UR5, Hololens, HTC Vive,…) there is an opportunity to create comparable results and to share algorithms – both for education and research. At the same me, a developed platform like this could be used by SMEs in order to start with AR/VR-based human-robot co-production. We propose to combine the current activities at the different universities and research institutions to create a EIT Manufacturing Mirror Lab ICT infrastructure, which divides the software maintenance effort between a couple of research institutions. As there are already existing components like for example IndustrialROS, it is possible to develop a functioning open source framework within a short amount of me, which can be used by all EIT Manufacturing partners and additional interested facilities in order to experiment for example with human-robot coproduction with AR and VR within education. The goal is to achieve ready to use software containers which are easy to install, if the hardware is already there. On the long run, the platform should furthermore enable to share algorithms or snapshots, so that also remote maintenance scenarios can be explored between different research institutions.

The SUPSI learning factory will function as a test bed in this project. For this purpose the addition of a collaborative robot to the factory is foreseen, the cobot will be used in an additional assembly station where it will collaborate with an operator.

4.5. VACMT

VACMT - To support the transformation of existing SME’s, Tier 1 & Tier 2's into volume automotive composite material suppliers - is also a project funded under the eit (European Institute of Innovation & Technology) Manufacturing.

SUPSI is a partner in this project and will carry it out together with:

- RISE SICOMP, project leader
- Slovak University of Technology in Bratislava

Concept:

The activity supports the transformation of existing automotive manufacturing companies currently supplying internal combustion engine (ICE) vehicles components, to manufacturing components for electrical vehicles. The transformation is based on being able to manufacture and source automotive component based on advanced composite materials which facilitates a greater flexibility in component design, supporting a greater flexibility in production, as well as light weighing. The reduction in ICE vehicles being sold coupled with a change to a more environmentally sustainable vehicles, represents a threat for these supplier but also carries great new business potential. During this transformation, the role of sustainable lightweight component in circular-economy-based business models need to be investigated. This activity is about supporting this transformation and setting up these businesses using the technology and methodologies developed in other projects.

Support the transformation of existing automotive Tier 1 and Tier 2 and their under subcontractors currently supplying internal combustion engine (ICE) vehicles components to being able to supply electrical vehicle components in accordance with demand. Key here is supporting the use of composite as a means of allowing more flexible production that can be adapted to rapidly changing designs and markets without costly investments. The transformation relies on using the latest advancements in materials and automation and concepts in circular economy. This means combining tested material structural and process modelling (RISE) and production simulation (STUBA) that can together support virtual manufacturing as a way of reducing risk, optimizing production and allowing for increase rapidity in implementing changes in productions. Alongside these is the development of business models (SUPSI) that allow for the implementation of circular economy. For this to be used effectively, the partners will be working closing with steering board member from OEMs and component manufacturers and facilitators to identify companies that need and want to adapt their production as well as to identify components that need adapting or producing from scratch.

SUPSI learning factory will serve as a testing bed in this project, with a particular focus on the development of a digital twin version more adapt for the specific goals of this project.

5. SUPSI Learning factory current and future developments

The SUPSI learning factory is being constantly updated on many different aspects. This brief paragraph contains a short description of the main developments that are being brought forward in addition to the various research projects, of which some examples can be found in paragraph 4.

5.1. Vision system

The learning factory is being equipped with a vision system dedicated to the presence detection of the production modules installed and of their postion.

These concepts are being brought forward for two main reasons:

- Measuring the position of the modules: this will allow to guide the robot path while it is interacting with the machines, for example loading or unloading the printing bed in the tangram pilot production. At the moment, in fact, the machines need to be carefully positioned and the robot path manually adapted. This translates in a very un-robust situation, in fact, whenever a collision happens or a machine needs to be moved, a manual intervention is required.
- Detect the presence of the machine and identify the type: this is crucial for the concept of plug-and-produce modules which we intend to fully implement. It is in fact foreseen that the factory will react and adapt its behaviour automatically depending on the available resources. For example a machine might break down and taken out of the factory for repair, in this case the system will reschedule its operations in order to

continue production (when possible) and to follow the given objectives and priorities.

The current state of this development is that a mechanical interface for the cameras has been already installed and we are in the process of finding the correct vision system for the job.

5.2. Cobot

In order to add a human-robot collaboration station to the learning factory it has been decided to install a collaborative robot, which will allow a safe setup to perform research activities in this field. Furthermore, this cobot will be of the anthropomorphic type, allowing for more complex handling operations that might be needed in many of the foreseen research projects with respect to the current SCARA robot (section 2.2.7).

Figure 33 Universal Robots UR5e

We are currently looking for the more suitable cobot for the job, which will probably be the Universal Robots UR5e (Figure 33). This model features 5 kg of payload and 850mm of reach, allowing to greatly increase the learning factory handling capabilities.

5.3. Agent-based scheduling

The current scheduling deployed in the SUPSI learning factory follows a traditional, rigid schema which requires the operator to create a queue of orders. The PLC than, rigidly orchestrates the factory in order to execute the pre-programmed basic operations. This approach does not account for any variation of the allowable resources nor for any modification of the order queue and, additionally, it does not optimize the operation sequence depending on any event.

The foreseen development, which is already under study, is to create in-house an agent-based scheduling software capable of boosting the learning factory elasticity and efficiency. The key goals of this new software will be:

- To optimize the use of resources, for example if there is an idle printer it might be better to start a new print immediately rather than waiting for the end of another operation, which is what happens today since it is very difficult to foresee these synchronizations offline (variable printing times are the main issue in this case)
- To react to variable resources availability, for example if a printer brakes down the system needs to be able to re-direct on other machines the parts to be produced; or do the same when an additional machine gets available.
- To react to variation in the orders queue, for example if a more pressing order comes in the factory needs to be able to immediately put on hold all possible activities and concentrate on producing this new order

Such a process is possible only if the correct information are available to the scheduler and, so, as this new approach gets implemented more and more sensors will be installed in the factory in order to permit it to correctly function.

A lot of literature can be found on these topics and it is a core tool of the I4.0 revolution.

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