Project "TESUN-83486178370409 finanziamento dipartimenti di eccellenza CAP. 1694 TIT. 232 ART. 6"

DIGEP - POLITECNICO DI TORINO

FIFTH YEAR REPORT

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This document is split into two main sections. The first section provides the research activity carried out in 2022 the last year of the project and some relevant results/achievements. The second section sketches the final entries of the project budget.

1 Research activity

As indicated in the project presentation, the aim of the research activity of DIGEP is to cope with the fundamental theme of man-machine interaction/integration, intermingling three complementary disciplinary areas, namely, the Technological Perspective, the Management Perspective, and the Economic and Legal Perspective. A quick sketch of the Department Research activity in 2022 is provided below and then the research main themes under the various perspectives are itemized.

1.0 General Overview

During 2022, the refurbishment of the MIND4LAB was completed and the research activities continued regularly. The goal of pursuing transdisciplinary projects was kept as a key indicator and several research groups continued being involved in joint projects. The overall volume of 2022 project publications significantly increased with respect to the one of the previous year.

We are pleased to announce that in 2022, six colleagues were promoted at Full Professor level: Eleonora Atzeni, Alessandra Colombelli, Domenico Maisano, Luca Mastrogiacomo, Guido Perboli and Elisa Ughetto: Eleonora, Domenico and Luca in the field of Technologies and Processing Systems; Alessandra and Elisa in the field of Management Engineering and Economics and Guido in the field of Operations Research. Also, another colleague, Viviana Molaschi, joined our Department as Associate Professor of Administrative Law. Overall now the Department presents in total 46 tenured (Full and Associate) Professors. In terms of dissemination, we mention that DIGEP successfully hosted at Oropa (BI) the 15th Workshop on Models and Algorithms for Planning and Scheduling (https://mapsp2022.polito.it/).

The Ministry of the University and Education positively evaluated our project in spring 2022 and this had as a consequence that we were allowed to compete to the next call of the Project "Dipartimenti di Eccellenza" for the period 2023-2027. We submitted our new proposal (whose core focus is on Digital Transition) in October 2022 and the outcome of this new submission is foreseen by the end of the year.

In the remainder of this section, we present a detailed description of the progress of research activities for the year 2022 under the technological, management, economic and legal perspectives, with reference to the specific research axes. For each of these activities, references to any relevant scientific publication produced during this last year are also given.

1.1 Technological Perspective

This section presents the progress in the last year of the project (2022), with reference to the seven technological laboratories, i.e.:

A – 3D modelling and simulation;
B – Design and simulation of new processes and systems;
C – Collaborative robots;
D – Additive production;
E – Factory logistics;
F – Quality and measurements;
G – Sustainability.

It should be noted that the acquisition and installation of new equipment/instrumentation had already been completed for all laboratories and that the use of this equipment/instrumentation was essential for a significant progression of research activities in the year 2022. The description of each of the seven laboratories is structured according to the following aspects (if applicable):

- Progress of research, especially that accomplished using the resources (e.g., instrumentation, personnel, software, etc.) acquired during the project;
- Main results and "achievements" (i.e., scientific honours and awards) related to the project's research activities;
- Scientific dissemination related to the scientific publications issued during 2022, concerning research activities that are relevant to the project. Each publication was

acknowledged with the statement: "*This research was partially supported by the award «TESUN-83486178370409 finanziamento dipartimenti di eccellenza CAP. 1694 TIT. 232 ART. 6», which was conferred by «Ministero dell'Istruzione, dell'Università e della Ricerca»*".

As for previous annual reports, the research activities of the seven technological laboratories are significantly interconnected and complementary to each other, as evidenced by several multidisciplinary publications issued in 2022, which involve multiple laboratories. The choice of reporting the results of each laboratory separately was made for reasons of comprehensibility and to give continuity to the annual reports produced in the four previous years (i.e., from 2018 to 2021).

A – 3D modelling and simulation

A.1 Research update

In the interaction of humans and computers, current research studies are investigating how computers can detect, process and react to human emotions, to develop emotionally intelligent information systems. The emotional monitoring topic represents a major challenge, since it transcends the boundaries of the hard sciences, reaching the so-called humanities. Four experiments (i.e., A, B, C and D) have been carried out during 2021 and 2022 and the results have been analysed and elaborated this year. These experiments concerned the acquisition of facial and physiological data, through the adoption of depth camera and EEG (electroencephalogram) helmet, during the view of "affective" images (experiment A), or the visit of novel Virtual Reality environments aimed at eliciting the five basic emotions anger, disgust, fear, joy, sadness (experiment B) or evaluating user's emotional reaction to colours (experiment C) and forms (experiment D). The goals were: (i) to create a public database of spontaneous facial expressions; (ii) to investigate the effectiveness of Virtual Reality in eliciting emotions; (iii) to understand which emotions are more typical of human-computer interaction context; (iv) to compare the results obtained with questionnaires, facial data and EEG; (v) to assess the ground truth of emotion.

A.2 Results and dissemination

Experiment A led to the creation of an "ecologically valid" 3D database of expressive faces of 104 subjects, described in detail in [A1]. It will be made publicly available after the

publication of the presentation paper. Also, a graphical design to display results was conceived inspired by balloon plots and introduced in [A2]. Experiment B allowed to create a database of validated affective Virtual Reality environments and then to compare questionnaire, EEG and facial data. After the validation of the environments with questionnaire responses [A3, A4], facial data have been analysed thanks to the adoption of two neural networks architectures, one for static 3D data based on Vision Transformers (ViT) [A5] and one for videos based on Video Transformer Network (VTN) [A6]. The comparison with EEG data was performed thanks to the adoption of a graphical framework which makes us of valence, arousal, dominance and engagement parameters (the presenting paper is currently in writing). The same parameters have been adopted to analyse EEG data obtained in experiments C and D, exploring the effects of colours and forms on the users [A7, A8].

The results of the experiments show that Virtual Reality is a valuable tool for eliciting emotions in the user, with disgust, fear and anger being the most aroused emotions; sadness seems less easily elicitable. The comparison between questionnaire replies, facial and EEG data shows a good correspondence between the three assessment methods, especially with the support of valence/arousal/dominance parameters, which suggest that basic emotions could be quantified depending on their positivity/activation/control.

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B – Design and simulation of new processes and systems

In 2022, the research team further advanced almost all the topics included in the 2021 report, with a constant flow of activities on smart manufacturing and predictive maintenance, process monitoring/control for lean production, process innovation towards human-machine collaboration and material sustainability. The activities are summarized in the following sub-sections.

B.1 Smart manufacturing

The availability of new research equipment and machines has enabled the experimental testing of new sustainable processes. The digital transformation has a key role in ensuring smooth joining processes, thanks to the on-line monitoring of processes. Thus, the research team faced the technological challenge to assess the reliability and repeatability of the joining processes, based on the detection of hidden anomalies in the joint. Machine learning algorithms were applied to support the operator in the evaluation of the tool degradation, and the real time assessment of the machine efficiency (predictive maintenance) or to predict the quality of spots. A result of this approach has been the development of a dynamic predictive model to evaluate the electrode wear through the monitoring of the welding parameters, such as welding current, electrode voltage, electrode displacement, etc. [B1].

B.2 Lean production

To face the increasing competition in the global markets and the consequent interest of many manufacturers to start the Lean transformation, the research team developed a tool able to consistently measure the undergoing evolution in the value stream selected, regardless of its extent, to take the subsequent actions needed [B2].

Furthermore, in a growing competitive environment, it is essential to have a clear idea of a product's total expenditure by estimating the component costs and correctly allocate cost drivers. Since assigning exact commodity consumption costs is one of the most complicated aspects of cost engineering activities, especially because in the design stage, information is not complete, the research team proposed a methodology to evaluate the proper commodity consumption during manufacturing activities for the assessment of the total part cost [B3].

Finally, a literature review was conducted to identify some specificities of production planning and control (PPC) activities specific for one-of-a-kind-production (OKP), to provide a theoretical overview of different PPC practices suitable for the OKP environment and insights for scientific developments in order to manage the complexity inherent in the OKP process [B4].

B.3 Human machine interaction

In order to improve the working conditions of the operators and enhance the product quality, the research team proposed a human-robot collaborative workspace for the detaching, removing and disposing of the metal sheet parts after laser cut. Such activity is typically performed by human operators because it is difficult to automate. Moreover, such activity is always tedious, sometimes dangerous, and often it is ergonomically heavy. The research presents a new approach using collaborative robots for the management of sheet metal cut parts, specifically for developing the removing and sorting tasks of the cut sheet metal parts from the blank skeleton [B5].

B.4 Material lifecycle management

Environmental concerns are increasingly demanding for sustainable consumption of Earth's resources. The adoption of the circular economy model can potentially address the environmental sustainability challenge, but there is a need to revolutionize the way products are developed. For this reason, the research team explored the current scientific literature related to the open product development process in support of sustainability, with a major focus on circular economy, and propose a framework to address the main obstacle emerged from it [B6]. Further details on the proposed framework for the material lifecycle digitization through the establishment of a digital material passport were also provided [B7].

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C – Collaborative robots

C.1 Research update

As part of the study of Human-Robot Collaboration (HRC), the following research activities were carried out during the year 2022.

- *Experiment to explore user experience and physiological response in HRC* [C1, C2]. This activity provided a novel study focused on the human aspects involved in industrial HRC by exploring the effects of various HRC setting factors (i.e., robot movement speed, proximity with robot workspace and control of execution time). In particular, the impact of industrial HRC on user experience, affective state and stress was investigated, assessed through both subjective measures (i.e., questionnaires) and objective ones (i.e., physiological signals). Participants' physiological responses (i.e., electrodermal activity and heart rate) were also collected non-invasively through the Empatica E4 wristband to monitor the amount of stress generated. Forty-two participants were involved in the study. Robot movement speed and control of the task execution time resulted to be the most influential factors. The results also showed the need for customization of HRC to improve ergonomics (both psychological and physical) and the well-being of the operator.
- *Experiment to analyze differences between manual and collaborative repetitive assembly processes*. A novel experimental setting involving a repetitive assembly task of a tile cutter was conducted to investigate the effects of prolonged HRC on user experience and performance [C3]. Each participant was involved in two four-hour shifts: a manual assembly setting and a HRC assembly setting. The data collected included perceived workload, self-reported affective state, perceived body exertion, physiological response

(collected non-invasively with the Empatica E4 wristband), and eye-tracking measures (obtained through the TobiiPro Glasses 3). Process and product defects were also monitored during the process. In the HRC setting, significantly less mental effort and process defects were observed with respect to manual assembly. This result highlighted how collaborative robots may support humans even from a cognitive point of view.

- *Experiment to explore the definition of assembly complexity in a collaborative process*. The concept of assembly complexity has been widely addressed over the years. The definition of a methodology to assess assembly complexity is a topic of primary concern in manufacturing given that it may enhance product defectiveness and thus companies' performances. In the light of introduction of cobots in production lines the traditional concepts of assembly complexity should be revisited. A preliminary framework to assess collaborative assembly complexity was proposed [C4]. An experimental campaign was conducted to investigate the impact of collaborative robotics on operators' perceived complexity and performances. Participants had to assemble three different products in two modalities (manual and collaborative) and then they were asked to compare in pairs the six assembly processes in terms of perceived complexity. Data collected involved: physiological signals (through Empatica E4), eye-tracking data (though TobiiPro Glasses 3), perceived workload (through NASA-TLX) and product and process defectiveness. The contribute of this study is two-fold: (i) it provided evidence that traditional assembly complexity assessment methods are unsuitable for collaborative processes and (ii) it showed that cobots help operators in successfully completing assembly processes, reducing defects and improving quality even with very complex products.
- *Predictive maintenance and scheduling of energy recharging of mobile manipulator through IoT*. The study [C5, C6] started from an online monitoring system implemented on the mobile robot in the laboratory, for sake of safety assurance. It allowed "to make a virtue out of necessity" by extending the scope of on-line monitoring to predicting failures and safe stops. This was done by implementing a platform, based on open access tools and technologies, to monitor the parameters of a robot during the execution of collaborative tasks. An automatic Machine Learning (ML) tool on the edge of the network can help to perform the on-line predictions of possible outages of collaborative robots, especially due to human-robot interactions. The on-line monitoring system allows to increase the reliability of collaborative work by (i) eliminating any unplanned downtimes during execution of the tasks, (ii) maximizing trust in safe interactions, and (iii) increasing the

robot's lifetime. The proposed framework demonstrates a data management technique in industrial robots, which is considered as a physical cyber-system.

- *Use of smart sensors in laboratory facilities, for remote online diagnosis* [C7]. The study describes the design and implementation of Automated Fault Detection and Diagnostics (AFDD) for office building systems. This work is part of larger research focused on distributed digital collaboration framework used in Facility Management. The implementation exploits some facilities within the Collaborative Robotics Laboratory and the experience on IoT gathered with the application to mobile robots. The objective is to allow remote/smart monitoring of the facilities, anomaly detection and fault diagnostics. A huge number of data can be gathered locally by smart sensors that are integrated and interconnected by Internet of Things (IoT).

C.2 Achievements

The paper written by Matteo Capponi together with professors Fiorenzo Franceschini, Luca Mastrogiacomo and Dario Antonelli, entitled "Product complexity and quality in assembly processes: state-of-the-art and challenges for industrial HRC" [C4], was awarded Best Student Paper during the 5th International Conference on Quality Engineering and Management.

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D – Additive production

D.1 Directed Energy Deposition (DED) of metal powder with laser beam

The Finite Element (FE) model, developed in 2021, was appropriate to simulate the various DED scanning strategies with piecewise constant process parameters and was verified on 316L single-track depositions. In 2022, we explored the forecasting capabilities of the DED model for depositing a complex thin-walled geometry made of 316L, adopting different scanning strategies. It is worth noting that the DED process leads to large temperature gradients experienced during the continuous melting, remelting and solidifications. These severe temperature gradients make defects like cracks or pores one of the principal problems once the deposition is terminated, caused by residual internal stresses [D1]. Many process parameters influence the temperatures reached during the deposition step, and experimental work is needed to tune process parameters, but this requires time and cost [D2]. The role of numerical simulation is to suggest the process parameters set that improves the thermal behaviour, thus reducing the need for experiments. The simulation model should predict the deformations resulting from the thermal stress during the deposition process and realize a stable, coherent, and meaningful simulation setup able to obtain reliable results about the thermal-structural history of the component designed and built. To evaluate the capabilities of the FE model, a complex thin-walled geometry to be deposited on a flat substrate was designed and in parallel the simulation was run, and the geometry was deposited using the LASERDYNE® 430 DED system. Different scanning paths have been studied for the desired geometry to highlight the differences between them in terms of thermal history and deformation outcomes and determine which ones can be used to obtain the minimal deformations. Results show that the scanning strategies which better emphasized the final deformations are one-way, single-track zig-zag, and c-sectors, while the spiral inward results in lower deformations [D3]. Regarding the simulation model, the mean temperature evolution is maintained varying the time step, but with a finer time step local thermal behaviour is also

captured. However, raising the time step increases the error of approximation but with a reduction of the computation time. The manufacturing process required two hours, so it makes no sense that the simulation takes more time. Thus, a compromise with the time step of 25 seconds was chosen, finding the correct balance between accuracy in results and computational costs. Outcomes revealed that the numerical model faithfully predicts the experimental results in terms of temperatures and deformations, the latter with an approximation error of less than 1 mm. The promising results suggest further investigations of alternative scanning strategies with non-linear paths that better follow the complex geometries typical of additive manufactured parts [D4, D5].

In 2022 the technical gas pipeline has been completed and the rotary-tilting table has been installed on the LASERDYNE® 430 DED system available in the laboratory. An experimental activity has been conducted to explore the geometrical capabilities of the 5-axes system, made available by the installation of the rotary-tilting table. The deposition of multiple complex features was investigated to study the possibilities and the criticalities of multi-axis Directed Energy Deposition of complex geometries. The experimental campaign evidenced specific issues related to the CAM software tools for generating the slices and deposition paths. Most problems derive from the translation of programming strategies for CNC machines, which suffer from the adaption from subtractive to additive production. The CAM software tools development shall move towards better inclusivity to involve Additive Manufacturing technologies in their regular application, and a strict integration of functions must be reached.

The programmed research activities were concluded in 2022. Future activities will rely on the mechanical characterization of hybrid components (i.e., deposits on a substrate). Dedicated equipment for temperature measurements during the LP-DED process is under testing, allowing the coupling of simulation and experimental analysis to fine-tune the prediction models and optimize the deposition process.

D.2 Automation in metal Additive Manufacturing (AM) production

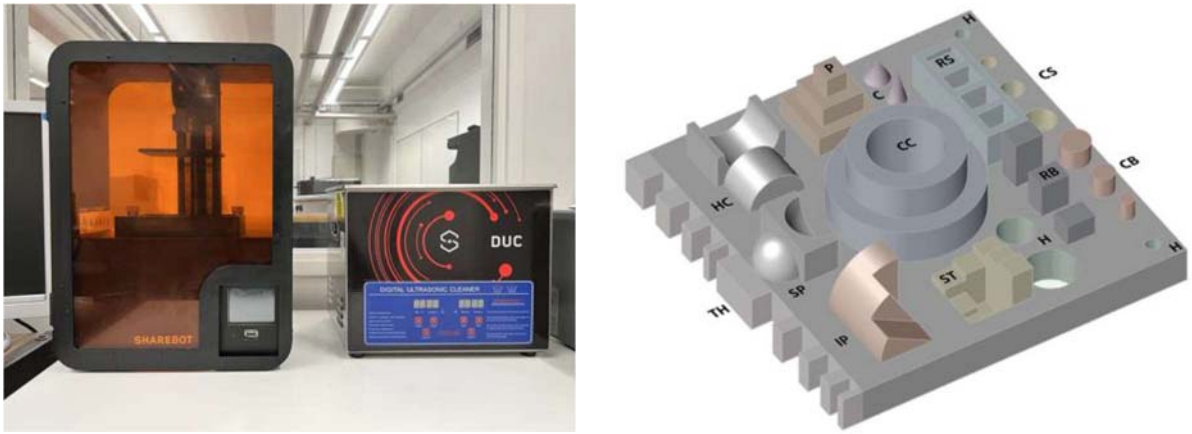
Finishing processes, or surface treatments, have always been used in industrial manufacturing. Today, more than ever, they acquire a fundamental role in producing components with high technological value together with the application of AM techniques, given the typical poor surface quality of AM components. In the framework of the project two finishing processes were evaluated to apply to AM components.

The OTEC vibro-finishing system, available in the laboratory, was used to evaluate the surface quality obtainable on complex features with internal cavities produced by laser powder bed fusion [D6]. Specimens with internal and obstacle geometries were produced in titanium alloy (Ti-6Al-4V) using a Concept Laser MLab-R system. The variation in surface quality was analyzed on the different surfaces before, during, and after the finishing process. As further analysis, the effect of a preliminary shot-peening operation was considered. Results show that the average roughness (R_a) of vibro-finished outer surfaces decreases by 66%, and 67% is obtained if shot-peening is performed. On inner surfaces, only a 10% decrease is obtained, which raises to 23% if shot peening is done. Outcomes show that vibratory finishing is a suitable process for finishing the outer surfaces of components made by Additive Manufacturing, but finish inner features is difficult to achieve through this process.

In parallel, the possibility of integrating laser ablation in the DED system has been investigated, using the same laser source for deposition and subsequent finishing. Alternating the two steps allows the laser beam to reach inner features and finish them before completion of the building process. A preliminary feasibility campaign has proved the potentiality of this approach and paved the way for a more extensive analysis of this hybrid application.

D.3 Fabrication of plastic parts by photopolymerisation

Polymers and photopolymers are the most used materials in AM with a much wider variety than metals or ceramics. The Direct Light Processing (DLP) technique was invented after the Stereolithography (SLA) process. As regards the dimensional accuracy and quality of DLP products, part deformation during the additive process is mainly influenced by the UV light intensity, the exposure time and the layer thickness as well as by the chemical composition of the resin. When printing aesthetical parts, the absence of surface defects and high quality of surfaces with a good definition of details. Conversely, when technical or medical parts have to be fabricated, the dimensional accuracy and manufacturing tolerances are of paramount importance. The dimensional and geometrical accuracy of 3d printed parts that is achievable with three different resins was investigated for a specific DLP printer, which is Rover by Sharebot (Figure D.1(a)). The study [D7] was carried out using a benchmarking approach that considers the printed replicas of a reference artifact (Figure D.1(b)) [D8].



(a) (b)

Figure D.1. Rover DLP printer by Sharebot (a); reference part (b).

The three tested resins are named S-Clear, G-Strong and S-Hard. Except for the S-Clear that is transparent, they present a neutral grey color and ensure optimal performances, both visual and mechanical. The 3d printed replicas of the reference part are shown in Figure D.2(a), (b) and (c), for the G-strong resin, the S-Hard resin and the G-clear resin respectively.

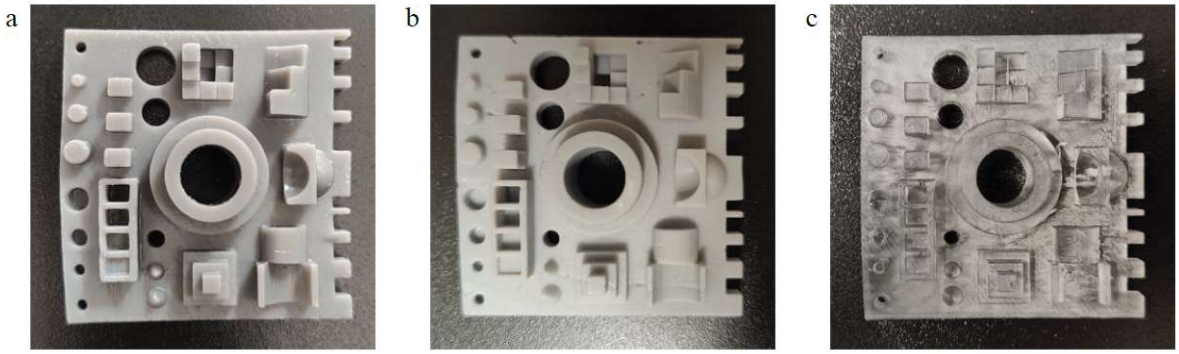


Figure D.2. Photos of the three replicas of the reference part: G-Strong (a); S-Hard (b); S-Clear (c).

The dimensional accuracy of the three resins was evaluated in terms of ISO IT grades (ISO 286) and standards of geometric dimensioning and tolerancing (GD&T). A general overview of the dimensional accuracy of each artifact replica is reported in Figure D.3, where a bar graph shows the 95th percentile values of the number of tolerance units n for the ISO basic sizes, while the grey horizontal bands represent the ranges of IT grades.

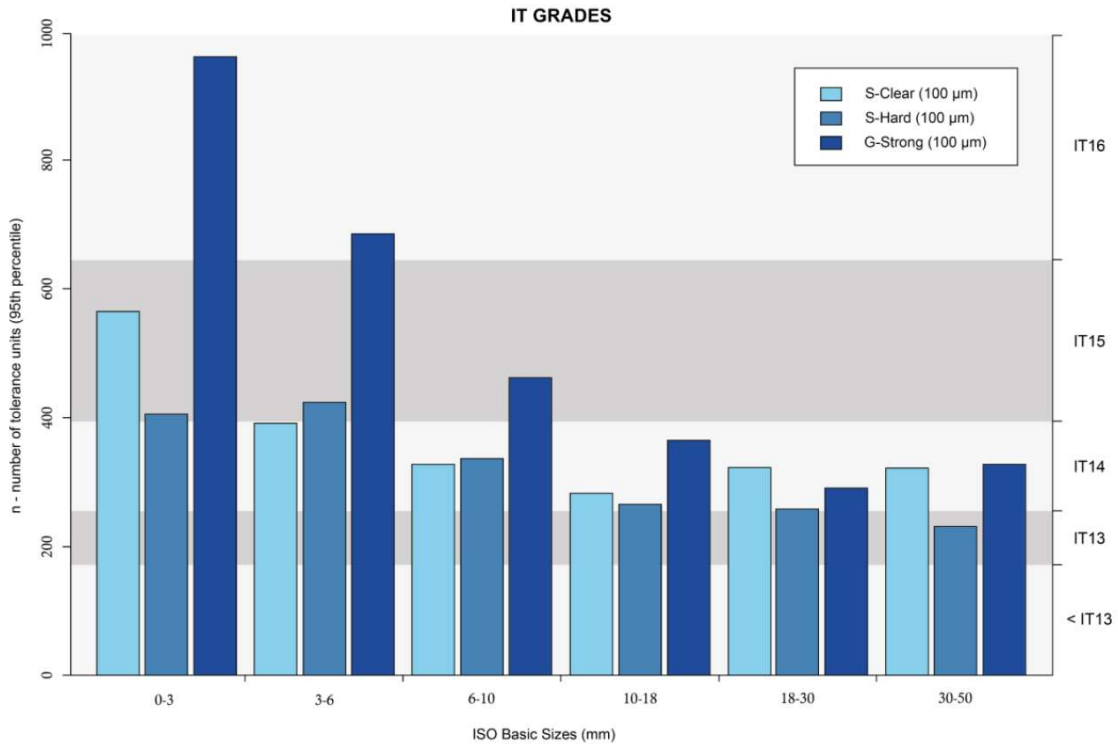


Figure D.3. Dimensional accuracy of the compared machines in terms of IT grades for different ISO basic size ranges.

The artifact replica made of the G-Strong resin has the worst dimensional accuracy. For the first two ranges of ISO basic sizes up to 6 mm, the dimensional quality of the G-Strong replica is IT16. For larger sizes, the accuracy improves for this replica and the grade IT14 is achieved for dimensions ranging from 10 mm to 50 mm. The accuracy of the Rover printer with the other two resins is better than that of the G-Strong replica. An ISO IT15 grade is achieved with S-Hard and S-Clear resins for the smallest sizes, while the best accuracy of IT13 is reached for basic sizes in the range of 30-50 mm.

D.4 DLP ceramic

Additive manufacturing (AM) of ceramics covers nowadays an important role in biomedical, chemical, aerospace and electronics industries for the ability to obtain objects with complex shapes and high level of customization. Ceramics are quite versatile materials because of their good mechanical resistance combined with excellent thermal resistance and chemical stability and their biocompatibility for bone tissue regeneration. Different AM technologies are available for ceramic parts obtainment, such as vat photopolymerization (VP), fused filament fabrication (FFF), binder jetting (BJ), and selective laser sintering (SLS). AM allows reducing costs in terms of processing time and energy consumption with respect to traditional technologies, including gel casting, tape casting, and injection moulding. Compared to FFF,

BJ, and SLS 3D printing, the VP processes, i.e., stereolithography (SLA) and DLP, enable the production of complex ceramic parts with maximum precision and optimum surface roughness. The extensive literature review conducted in 2022 [D9] highlighted the main goal in producing 3D ceramic parts via VP processes which are to obtain a high-density green ceramic, leading to higher mechanical properties after sintering. The development of highly loaded ceramic suspensions (typically 45–55% by volume) within a printable viscosity (within the range of 3,000-5,000 mPa·s) is the key to achieving this goal. In the past decade, a few researchers focused on developing low viscosity photosensitive ceramic suspensions loaded with various ceramic powders for DLP or SLA 3D printing technologies. Although the concept of preparing the ceramic resin is similar to the SLA and DLP processes, there are also some differences due to the different photopolymerization sources: the rheology (viscosity and flow) of the ceramic resins must be modified and optimized for each process, the photo-initiator system is different for each case and requires in-depth studies to evaluate the effect of the different light absorbers to achieve the desired accuracy for each system. At the beginning of the development of ceramic resins for VP processes, the viscosity of the suspension had to be comparable to that of the pristine raw resin, i.e. less than 3,000 mPa·s, while the current VP printers are also able to work on suspensions with a viscosity of tens of Pa·s. However, this is often difficult because, on the one hand, a higher volume fraction of ceramic particles allows for less shrinkage and higher density (and therefore mechanical strength) after sintering. On the other hand, a lower ceramic load reduces viscosity to a minimum and avoids possible segregation of the solid content. Therefore, compromises need to be made. To overcome these difficulties and make ceramic additive manufacturing more industrially feasible, several commercial inks based on alumina, silica and zirconia are already available on the market. Between industrial ceramic resins, Porcelite® resin is a ceramic suspension characterized by porcelain clay dispersed in an acrylic monomer base which starts polymerization when excited by a light source at the wavelength of 405 nm. Applications for Porcelite 3D printing include specialized manufacturing, automotive, aerospace, engineering, architecture, design and more. Given the possible applications in the aerospace field, in order to study possible applications in the context of two projects commissioned by ESA, a study was conducted to compare the processability of two different kinds of Porcelite® resins that are today available on the marketplace [D10]: PU, dedicated to all types of 405 nm DLP systems according to manufacturer's indication, and PB, a denser resin specifically thought for producer's 3D printing system. The influence of process and post-process parameters on cracks formation and dimensional accuracy were evaluated for

both resins. First, the experimental process plane was set using DoE approach. X-ray diffractometry (XRD) and field emission scanning electron microscopy (FESEM) analyses were conducted to evaluate the granulometry of the powder. Thermogravimetric analysis (TG) and differential thermal analysis (DTA) analyses validated the firing profile for the thermal post-treatment. Investigation on crack formation in fired samples, post-printing and post-sintering dimensional evaluations were performed to compare printing accuracy and final volumetric shrinkage.

Different characterizations for the PB resin, the most loaded, were performed. Viscosity measurements revealed the relatively constant viscosity trend in relation to shear rate, a yield stress of 5.8 Pa and a Bingham viscosity of 37.2 Pa·s at a shear rate of 10 s-1 were found. Similar values were found in literature for resin with comparable solid loading. In the preliminary test, the problem of the cracks formation during the thermal treatment has been studied, and the window of process parameters that allow obtaining acceptable results has been determined. TG-DTA established a firing cycle different from the producer's recommendations, but cracks were still present in the PU resin samples. Furthermore, the cycle proposed needed a long working time, and the presence of cracks did not justify the loss in productivity. The results of this study highlighted the importance of knowing the exact composition of the resin used in stereolithography applications, in order to predict the optimal process and post-process conditions and to obtain dense objects with adequate dimensional and mechanical properties for the desired applications. This study highlights that the processability of commercial resins with unknown composition and solid load leads to difficulties in several aspects, so a thorough investigation is required to understand the specific process.

D.5 Sonicator

The term sonication refers to the use of ultrasonic acoustic waves where it is necessary to disintegrate cells, homogenize, emulsify and disperse products. In the laboratory, sonication is normally carried out by means of a sonicator which generates mechanical vibrations produced and amplified by a generator. The ultrasounds are transmitted in a tank containing water, which can also be thermostated at various temperatures. The main use and reason for purchasing the sonicator is the ability to clean metal samples produced by laser powder bed fusion (L-PBF) technology from particles that are not completely melted. In particular, it allows the removal of such particles from internal channels otherwise difficult to reach by

other means based on the length and geometry of the channel. This tool is proving to be fundamental for cleaning satellite antenna components produced using L-PBF technology in which the smallest surface deviation from the normal surface causes signal propagation disturbances with related problems in the use of the components produced. The purchase of this instrumentation is allowing not only the multidisciplinary collaboration between materialists and technologists but also the possibility of acquiring knowledge that can lead to future research contracts with end users such as ESA.

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E – Factory logistics

E.1 Research update

Below are the main activities conducted during the year 2022, related to the following topics:

- Pick-to-light displays;
- Use of the laboratory for students and companies operating in the logistics sector;
- Warehouse Digital Twin.

In particular, it is confirmed that pick-to-light displays have been activated to make the picking and replenishment operations of our automated warehouse faster. In addition, the logistics laboratory was used as a teaching tool for master's and bachelor's degree students. Finally, comparison meetings were held with companies in the area and in other regions of Italy for a use of the logistics laboratory as a tool for teaching and understanding logistics issues. Regarding, the warehouse Digital Twin please refer specifically to the sections below. With respect to last year's report, research efforts have been directed towards consolidating the Digital Model part of the warehouse Digital Twin, as follows.

Digital Model (DM). The DM developed in 2021 was further refined. The structure of the model is depicted in Figure E.1. Once having consolidated the model structure, it was implemented in AnyLogic, a Java based multi-method simulation software employed in various industries.

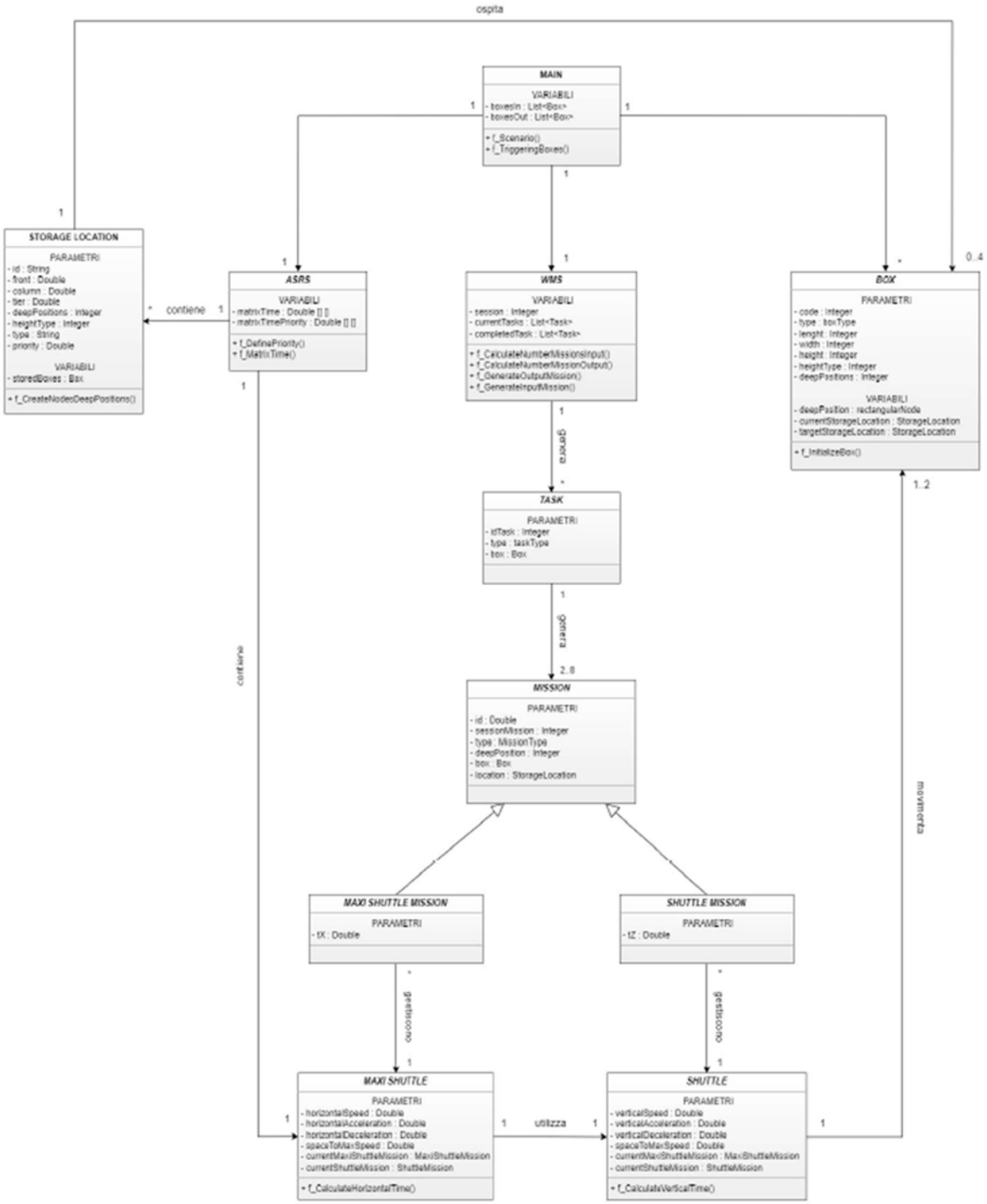

Figure E.1. Model structure.

At the current level of implementation, the DM only replicates the automated area of the Logistics Laboratory and the movement of totes. Elements like the Mobile Industrial Robots (MIR) fleet, the operators and the products are still missing. The model was built following a modular approach. Therefore, the main constituents of the Logistics Laboratory were identified and separately modelled in AnyLogic as independent agents. Moreover, reproducing the single elements of the real system as independent objects was useful to

model the specific functioning, rules, and exceptions and to reach a high level of detail in the virtual system. Figure 2 shows the DM in the AnyLogic environment.

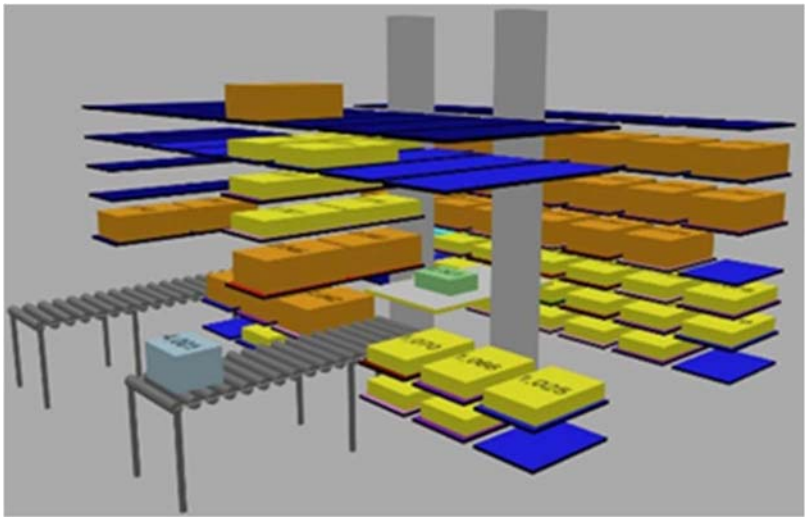

Figure E.2. The digital model.

DM validation. The DM was validated in order to test its reliability in replicating the functioning and performance of the real system. In particular, the storage process was analysed. A validation campaign based on the principles of the Design of Experiment (DoE) was set. Specifically, the total time to carry out the process was selected as dependent variable, while the tote type, the total number of totes and the starting storage capacity used were considered as independent variables (Table E.1). For each combination of factors, a replication was performed. Considering the levels of the factors and the replications, a total of 72 experiment were conducted. Finally, the storage locations selected by the Maxi Shuttle to store the totes were recorded. Once conducted all the experiments in the Logistics Laboratory, the same DOE configuration was exactly replicated in the DM. After repetitively adjusting the model parameters and re-running the simulations, thanks to this approach, it was possible to achieve an average of 0.40% delta between the storage time of the laboratory and the one simulated with the DM.

Table E.1. DEO structure.

		Factors		
		Tote type	Number of totes	Starting storage capacity used
Levels	1	Type 1	6	0%
	2	Type 2	13	27.5%
	3	Type 3	20	55%
	4	Type 4		

E.2 Teaching

The laboratory was also used for teaching activities. Specifically, a laboratory experience organized in 10 sessions was proposed to a group of more than 60 students of the Industrial Plants course (bachelor's degree in Management Engineering) and Industry 4.0 for Production Systems course (master's degree in Automotive engineering, academic year 2021-2022), selected on a voluntary basis. The experience consisted in reproducing the main warehouse operations of a fictitious company operating in the e-commerce sector. Therefore, the students were asked to perform kitting/picking operations, use the IT systems of the warehouse and work with the MIR fleet. At the end of the experience, a questionnaire was administrated to the students in order to assess their level of awareness and interest toward logistics processes, and to evaluate their point of view about the main impacts of automated warehouses on the processes of a distribution centre.

Moreover, a similar experience was done with all the students of the Supply Chain Management course (master's degree in Management Engineering, academic year 2021-2022), and Industry 4.0 for Production Systems course (master's degree in Automotive engineering, academic year 2022-2023). Due to a smaller number of students, 2 sessions for each course were set. Also in this case, the students were asked to perform kitting/picking operations, use the IT systems of the warehouse and work with the Mobile Industrial Robots (MIR) fleet, but no questionnaire was submitted at the end of the experience.

E.3 Training

The availability of the automatic system has been communicated to many companies in the logistics sector, in order to make the system an area in which to carry out training for the companies themselves. At the present time, three possible opportunities have opened up:

- the Incas company, builder of the warehouse, could use the system in promotional terms, experimenting with new storage logics and training the newly hired technicians;
- the organizational consulting company Kaizen, would like to use the system for training activities for its consultants and customers, creating a comparison between the automatic system and lean approaches, allowing to combine automation and reorganization of operations;
- MBM, supplier of the management software/MRP, would like to use the plant as a demonstrator for its customers.

All these activities would be cost-effective for the companies mentioned and would allow an increase in consulting funds for the DIGEP.

E.4 Software applications

MRP module. In the pipeline of fully introducing an ERP software for the Logistics Laboratory, an MRP module was installed in the IT system. Specifically, the company MBM provided the product called GPS (Global Planning System). It consists of web-based platform exploitable for material and resource planning activities. It offers a complete visibility of the entire production process and some innovative techniques for forward planning. Moreover, it can be integrated with all management systems of the laboratory from which it receives the necessary data.

Virtual machines. In 2022 a cloud environment for building ad hoc virtual machines has been setup with Oracle. We have thus built multiple virtual machines upon which the Warehouse Management System (WMS) and ERP software are installed. Both software are now up and running. This shared environment will make the communication and interconnection between the two software easier and quicker.

E.5 Dissemination

In 2022, the logistics laboratory was presented at the following events:

- Automation & Testing 2022 (A&T), which is an international automation fair for companies and research centres;
- IX PhD on the go "MARCO GARETTI", Doctoral Workshop SSD ING-IND/17, Università degli Studi del Sannio, Benevento, 16th – 17th June 2022;
- Biennale della Tecnologia 2022, Torino.

A paper comprising the DT architecture and the results of the DoE for the DM has been presented at the international conference MIM 2022 and published on the corresponding journal. An extended version of this paper is underway for publication in a correlated special issue. Furthermore, a paper depicting the results from an experiment to Bachelor and Master students has been presented at the XXVII Summer School "Francesco Turco" International Conference.

In 2022 three M.Sc. students have been supervised during their theses, namely Dario De Luca, Stefano Bonfitto and Federico Ruspolini. The three students have been deeply involved in both developing Digital Model upon the Anylogic simulation environment and validating it

through the experiments in the laboratory. Their results helped shape the afore-mentioned publications.

E.6 Equipment

Contacts have been made with companies specializing in the creation of workstations, development of RFID applications and exoskeletons.

Ergonomic workstations. Some model configurations have been defined to be adopted within the spaces of our laboratory capable of facilitating assembly activities of objects from components and semi-finished products, contained within the automatic warehouse. These configurations must be capable of allowing subsequent re-layout operations so that the benefits of changes in logistical and production processes can be objectively evaluated. The inclusion of karakuri solutions in conjunction with workstation loading/unloading points is also likely.

RFID applications. The issue of the application of RFID technology for the traceability of components, semi-finished and final products along the entire internal supply chain of our laboratory has been analysed with companies in the field. In particular, we would like to equip our two automatic guided vehicles (AGVs) with specific gates so that we can have two mobile gates that can easily change the configuration of our layout.

Exoskeletons. Preliminary tests were conducted with exoskeletons for an initial assessment of the benefits of using this equipment as an aid to operators in the picking and refilling stations of our automated storage system.

E.7 Achievements

At present, the realization of the warehouse and the automatic transport system, which we recall is unique in Italy, have allowed the development of research activities, already implemented in the aforementioned publications; an innovation in institutional teaching allowing many students to enjoy a laboratory experience, not otherwise achievable; to communicate to the corporate world the presence of a system available at the university for experimentation (see for example, the presence at the A & T Fair in Turin in February 2022); the inclusion in Mind4lab of a logistics area that will be integrated into the production processes of the other equipped areas of the laboratory. The possibility of creating a network of universities that have logistic laboratories of different types cannot be excluded.

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F – Quality and measurements

F.1 Research update

During the year 2022, the planned research activity on advanced methods for technological surface characterization has been completed. It tackled both mechanical characterization by means of non-destructive test, i.e., nano- and macro-instrumented indentation test, and multiscale geometrical characterization by means of optical inspection performed by surface topography measuring instrument. The research was directed towards the development of smart algorithms to achieve robust, accurate and precise characterisation towards zero-defect manufacturing. The research on mechanical characterization mostly focused on deployment at industrial level to enhance quality controls. The research on topographical characterization focused both on the development of innovative Machine-Vision aided characterization methods and on the application on industrially relevant state of-the-art case studies.

A further research strand focused on the development of methods to plan quality inspections based on probabilistic models and defect generation models. Furthermore, novel approaches to statistically control assembly processes were developed through the definition of control charts and diagnostic methods based on defect prediction models. Extensive research was additionally devoted to studying the effects of product complexity in assembly and disassembly on process time, defects, and operators' learning rates. Further research activities focused on the study of quality control procedures performed in human-robot collaboration systems. Quality inspection procedures were developed catering for the specificity of the environment, and characterisation methods based on AI methods, including machine vision, ML, and data augmentation and data fusion, are being study for technological surface characterisation. Finally, new research insights concerning investigation of the use of Digital Twin for quality control in human-robot collaboration environments were gathered.

F.2 Deliverables

- *Surface topography characterisation for advanced technological applications:*
  - Development of methodology to evaluate measurement uncertainty of surface topography-based methods to estimate wear volume in pin on disc test;
  - Metrological comparison of state-of-the-art topographical methods for wear volume estimation in in pin on disc test;
  - Integration of surface topography measuring instrument to a cobot and development of a metrological framework to improve multi-scale topographical measurement.
- *Surface topography characterisation for Additively Manufactured surface* (in collaboration with IAM and cross-disciplinary with "Technological Perspective" part D):
  - Development of a machine learning algorithm to classify native surface topographies by EBM;
  - Development of an information—rich predictive model of internal defectivity based on non-destructive characterisation;
  - Study of the effect of part geometry on surface topography of thin-walled structures by EBM.
- *Non-conventional hardness testing*
  - Development of bootstrap methodology to evaluate measurement uncertainty of indenter area calibration in nanoindentation;
  - Development of in-situ contact resistance measurement to improve accuracy and precision of mechanical characterisation by nanoindentation;
  - Application of nanoindentation to characterise composite multilayer coating for tribological applications;
  - Development of statistical methods to non-destructively characterise thickness of composite multilayer coating for tribological applications by augmented nanoindentation.
- *Study, implementation and planning of quality inspection procedures in manufacturing processes:*
  - Study of laser welding process optimization based on Machine Learning techniques;
  - Development of a tool for inspection planning based on defect prediction models and inspection strategy maps.
- *Study of product complexity in assembly and disassembly*

  - Analysis of the effects of product complexity in assembly and disassembly processes on process time, defect generation, and operator learning rates;
  - Study of the relationship between objective product complexity and human perceived complexity.
- *Performance measures of quality inspection strategies:*
  - Probabilistic model for quality control effectiveness for zero-defect manufacturing;
  - Performance measurement for offline inspections under variable interactions and inspection errors in low-volume production.
- *Defect prediction models for Statistical Process Control:*
  - Development of defect prediction models to improve assembly processes in low-volume productions;
  - Development of a novel defects-per-unit control chart for assembled products based on defect prediction models;
  - Preliminary investigation of the use of Digital Twin for quality control in human-robot collaboration.

F.3 Personnel formation and recruitment

To finalize the research topics, several new resources were acquired and trained:

- Two undergraduate students for final projects in Mechanical Engineering and Industrial Manufacturing Technologies B.Sc. degree;
- Eight graduate students for final projects in Mechanical Engineering and Management Engineering M.Sc. degree.

F.4 Instrumentation

The totality of the equipment of the laboratory of quality and technological surface characterisation was acquired and is operational. Specifically, the following items were fundamental for the aforementioned research activities and the achievement of related deliverables:

- Instrumented indentation testing platform STeP6 by Anton Paar for the nano (NHT3) and micro range with micro-scratch capability (MCT3);
- Macro-scale Instrumented Indentation Tester AXIOTEK ISRHU09;
- Coherence Scanning Interferometry Zygo NewView 9000;
- Software license for surface topography analysis: Digital Surf MountainsMap;

- Focus Variation Infinite Focus Sensor IF R25 Alicona to be mounted on robotic and cobotic arms to provide topographical measurements of large freeform objects;
- Modulus and equipment to perform augmented instrumented indentation test via electric contact resistance.

The laboratory is completely operating in the definitive location, i.e., the newly built and furbished metrological cell. As expected, all the equipment which was damaged by the fire happened in the former location has been returned and is fully operating.

F.5 Strategies for project sustainability

The research was carried out maintaining collaboration relationships with the following academic and industrial partners:

- Ultraprecision Surfaces Group (Prof D.A. Lucca) – Oklahoma State University (OK, USA);
- Manufacturing Metrology Team (Prof R.K. Leach) – University of Nottingham (UK);
- STAM – Science and Technology in Advanced Manufacturing Team (Prof R. Lupoi) – Trinity College, Dublin (IRL);
- Department of Mechanical Engineering (Prof H.N. Hansen – Prof Tosello) – Technical University of Denmark, Kgs. Lyngby (DK);
- Department of Mechanical Engineering (Prof. S. Beretta) – Politecnico di Milano (ITA);
- Department of Industrial Engineering (Prof E. Savio) – University of Padova (ITA);
- Department of Applied Science and Technology – DISAT (Prof P. Fino) – Politecnico di Torino (ITA);
- Department of Mechanical and Aerospace Engineering – DIMEAS (Prof L. Mazza and Prof A. Mura) – Politecnico di Torino (ITA);
- Laboratoire National de Métrologie et d'essai LNE (Dr. H. Nouira) – Paris (FR);
- Force Research Laboratory (Dr. A. Germak) – INRiM (ITA);
- Dimensional Metrology Research Laboratory (Dr. M. Zucco) – INRiM (ITA);
- TriTec (Dr. Pavel Sedmak) – Anton Paar, Graz (AUT);
- Engineering Digital Technology (Dr. A. Riccabone) – Avio Aero (ITA);
- Global R&I Materials (Dr. N. Li Pira) – Centro Ricerche FIAT CRF (ITA);
- Axiotek (Mr. D. Affri) - Induno Olona (ITA);
- AGLA Power Transmission (Mr. S. Bonù) – Sant'Ambrogio di Torino (ITA);

- L.B.N. Ricerca (Dr. R. Cagliero) - Sant'Ambrogio di Torino (ITA).

New collaboration relationships were established with the following academic and industrial partners:

- Prof. Ron S. Kenett, KPA Group and Samuel Neaman Institute for National Policy Research, Technion, Haifa, Israel;
- Dr. Hussein Naseraldin, ORT Braude College of Engineering, Karmiel, Israel;
- Dr. Itai Dattner, University of Haifa, Haifa, Israel;
- Dr. Uwe Brand - Dr. Daniel Heisselmann – Dr. Sonja Schmelter, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany;
- Mr. Domenico Laguzza, Olsa SpA, Moncalieri, Italy.

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G – Sustainability

The research activities of the fifth year were based on the achievements already established in the previous years of project. In particular, according to the fourth year report, the developed approaches and frameworks were applied to case studies of industrial interest, with the aim of quantifying the sustainability of both Industry 4.0 enabling technologies and conventional manufacturing processes within the life cycle of materials and products. The equipment, process monitoring systems and software for Life Cycle Assessment which have been acquired during the previous years of the project were employed to this purpose.

For the sake of exemplification, the production route of a cutting tool has been assessed by including the modeling of feedstock material production and manufacturing processes. The Cumulative Energy Demand and CO_2 emissions relative to the material flows, the consumable resources and the energy, were quantified. The approach, which monitors all these aspects, has been aimed at identifying the weakest points of the manufacturing line that need to be optimized. According to the obtained results, the electric energy consumption was the most impactful factor, followed by the incoming feedstock material production. An increase in use of material from secondary production (or an increase in end-of life material recycling) was suggested, as well as the use of greener energy mixes [G1].

Moreover, following the previously-published studies on WAAM + machining hybrid processes, methodologies that can be used to assess the effects of variations in the process parameters on the energy consumption of a Cold Metal Transfer (CMT) additive manufacturing process were developed. The analyses were carried out both at the process

level and under cradle-to-gate system boundaries. Demonstrative industrial case studies, derived from other research and consultancy projects, proved that variations in the two CMT deposition parameters (namely, the wire feed speed and the travel speed) affect both the energy consumption of the additive manufacturing system and the material deposition efficiency [G2]. Among the 6Rs of sustainable development, the impact of re-manufacturing, repair and recycling on environmental metrics was further studied, and parametric models were set for repairing procedures to be performed by means of metal wire deposition processes.

Finally, aiming for a more holistic assessment at a higher system-level, which embraces all the three pillars of sustainable development, a framework for the health risks assessment within an interconnected and sustainable manufacturing environment was studied. In such framework, an intelligent decision-making support system has been developed based on machine learning for operator healthcare monitoring in an Industry 4.0 manufacturing context. This could be part of a cloud manufacturing platform able to collect and process physiological, environmental and manufacturing process data for occupational health risk assessment to enable prompt action and prevent fatalities. At the present stage of research, a machine learning framework has been developed for input data classification as well as for the assessment of health risk level and type for the operator [G3]. Ongoing research efforts are aimed at building up a Human-Centered Cyber-Physical System aimed at defining and evaluating relevant Key Performance Indicators to enable task reassignment, job rescheduling and the impact of environmental policies on the operator health and safety.

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1.2 Management perspective

The managerial perspective on the relationship between technological change (due to digitization and to the Fourth Industrial Revolution) has been developed around the research trajectories illustrated below. Taken altogether, these streams of research aim at identifying the different effects of technological change on work and organizations, on the influence of algorithms on decision making processes and production systems.

H – Technological change

In the last year, the activity focused essentially on subaxes H.1 Technological change, innovation diffusion and competitive dynamics, H2. Technological change, managerial tensions and technology transfer challenges and ecosystems for SMEs, H.4 Technological change, skills and work design and H5 Innovations for corporate sustainability, while keeping on standby subaxis H.3 Technological change, managerial tensions and technology transfer challenges and ecosystems for SMEs.

H.1 Technological change, innovation diffusion and competitive dynamics.

This research trajectory is taking into consideration the impact that the technological change due to digitalization and investments in Information Systems (IS) and digital technologies have on competitive dynamics and on value creation. In 2022 the core of the activity has been manifold.

The tourism sector has been a first important research setting. In 2022, the first salient published paper [H1] examined the role that contingent factors can play in reducing the negative impact of Airbnb on the profitability growth of traditional players of the tourism sector, namely independent hotels, for understanding how the competitive dynamics are changed by new online platforms that enter in the industry. In the same year, another salient research outcome published consisted in a paper [H2] that analysed a unique dataset for investigating how digital peer-to-peer (P2P) platforms enable the creation of value for players that operate on these online platforms. This paper was co-authored with a Professor of Audencia Business School, who is highly recognized at international level.

Related to this research stream, the Department has also under review and is working on other three papers. The first paper [H3] investigated the impact of the COVID-19 pandemic on the P2P accommodation sector for understanding how an unprecedented shock affected the economy and the society as a whole. This study used a dataset composed of 2,041,966

property-day data points composed of 69,727 properties in all the 21 Italian regions in the pre and post-COVID-19. Results showed that travelers prefer rural (versus urban) P2P accommodation after the pandemic as well as price premium accommodation compared to the pre-COVID-19 period, highlighting the necessity of defining new policies and incentives for boosting the tourism in rural areas. In line with this direction, the second paper [H4] entered the flourishing debate about the effects of digital platforms on local economic welfare, estimating how the entry of a home-sharing platform affects the entrepreneurial activity and global economic outlook in local rural destinations. The authors of this paper contended that when economic conditions are declining, namely in rural areas, the entry of the platform can stimulate the entrepreneurial activity and consequently the local economy of marginal areas. The authors tested these arguments on the case of 270 Italian Borghi from 2009 to 2019 and the respective entry of Airbnb applying a quasi-experimental study with a difference in difference approach to the extent that both treated and untreated local markets are identifiable. The results showed that the entry of the online platform caused significant increase in the entrepreneurial activity (income from entrepreneurial activity, per capita income from entrepreneurial activity and number of active firms) with effects permuting thought all the value chain, starting from downward services (e.g., restoration) to upstream sectors (e.g., agriculture), highlighting important policy-maker implications. The third paper [H5] investigated the way service providers who operate on an online P2P platform adapted their strategies to face the Covid-19 pandemic. With an empirical investigation on a dataset of Airbnb listings in Rome from January 2018 to December 2020, the authors provided a threefold contribution by investigating: 1) how Airbnb hosts reacted to the Covid-19 and their strategic response; 2) the effects of these strategies on their economic performances; and 3) customer screening mechanisms allowed by the emerging segments and the corresponding strategies adopted to sort them.

A second field of research has analysed the role that the industry environment has in determining what is a correct alignment between the firm's business strategy and the use of IT (either for cost reduction or for customer's benefit improvement). The main contribution of the study (H1.6) lies in theorizing and empirically validating a new taxonomy of industry types based on the way IT must be used strategically to have performance impact based on the industry characteristics and the type of product and processes.

Finally, a third research stream has taken into analysis the determinants of Artificial Intelligence diffusion at the firm level. This line of research focuses on the determinants and the effects of firms AI adoption.

As for the determinants, the role of organizational, technological and external contexts is used to explain firm's propensity in AI technology adoption. More precisely, the empirical analysis conducted on a sample of 13.516 firms over the period 2004-2020 reveals that the recombination of both internal knowledge – investment in internal R&D and information and communication technologies (ICT) - and external knowledge – knowledge spillovers, buying R&D and knowledge collaboration with partners - are key predictors of AI adoption.

The adoption of Artificial Intelligence (AI) through the recombination of internal and external knowledge, in turn, affects resource allocation and firm innovation. One results (H1.7 and H1.8) allow to re-examine to what extent knowledge collaboration and resource allocation in R&D and ICT are complementary for innovation, controlling for in-house adoption of AI technology as a moderator. More precisely, using novel data on 14,143 firms over 2004-2020, we link investment in internal and external R&D as well as collaboration with different types of external partners as resource allocation strategy for innovation. We find a consistent inverted U-shape relationship between internal and external resource allocation and firm innovation with AI positively moderating it. This is due to the fact that the use of AI reduces costs of knowledge management and decision-making. In addition, the contribution of AI differs with the type of external collaboration partner for firm innovation. Taken together, these results call for a fundamental rethinking of mechanisms and strategies of resource allocation for firm innovation.

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H2. Technological change, managerial tensions and technology transfer challenges and ecosystems for SMEs

In 2022 the capitalization of the research outcome on this line has been focused on two dimensions of understanding.

First, the role of local universities in the technological specialization processes of regions has been investigated (H2.1). The research has been the outcome of a project financed by the European Patent Office. The research aims at analyzing the dynamics of co-evolution between the technological specialization of European regions and the patenting activities of co-localized universities. Although the importance of universities for the creation of new technological knowledge and the development of local ecosystems for innovation has been widely recognized, their role in regional branching and diversification patterns has been almost neglected by the extant scientific literature. The empirical setting relies on a dataset of 846,440 patent families, the output of 256 European regions and 428 local academic institutions. The results of the research indicate a robust and positive relationship between the technological entry of the universities and the specialization of the region in the same field. Furthermore, the technological distance between the portfolios of inventions filed by academic institutions and that of co-localized firms is negatively correlated with the subsequent specialization of the hosting region, and this relationship is amplified in the case of university entry. The results are also tested on sub-samples that distinguish technological fields with lower and higher complexity and geographical regions with lower and higher innovative performance. The previous relationships are confirmed only for high-tech and medium-high-tech fields and strong and leader innovators. This suggests that i) academic developments are more conducive to regional specialization when they relate to more complex technologies owing to the presence of localized spillovers, susceptible to geographical distance; ii) the entry of universities into new technology fields occurring in a

more developed local innovation ecosystem favors the subsequent specialization, thanks to existing collaborations and transmission channels.

Second, the different drivers that affect the process of transformation of the knowledge bases within local innovation systems (H2.2.). The research has been the outcome of a project financed by the European Patent Office. The research aims at provide new evidence on the co-evolution patterns of the technological specialization of innovation activities of firms and academic institutions located in the same European region. More specifically, the work aims at exploring to what extent and under what conditions there have been in place convergent or divergent processes in the relative specialization of the innovation activities carried out by co-located firms and universities. The research exploits a novel and unique dataset merging data on EU-funded R&D projects, universities, patents, and economic region-level data for a large sample of universities and firms co-located in geographical areas at the third level of the Nomenclature of Territorial Units for Statistics (NUTS3), which correspond to a sub-regional scale of analysis. Results indicate the presence of substantial heterogeneity across the analyzed EU regions with respect to the co-evolution of industry and academia specializations. In particular, results suggest that the specialization into a new technological domain is led by the local academic research system only in a few cases. We also document that a number of factors, at both the university and region levels, are associated with convergent or divergent processes in the relative specialization of the innovation activities carried out by firms and universities co-located in the same region.

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H.4 Technological change, skills and work design
This research line has been advanced by investigating three topics.

A first type of research has been related to investigating the impact of data-driven decision-making (DDM) on operational performance. Thanks to an international collaboration, a transnational survey of 138 Italian and US automotive supply companies was conducted, supported by plant visits and interviews. The results illustrated in a paper [H4.1] showed that a higher degree of data integration in information systems increases the positive effect of DDM on the probability of cost reduction and that the introduction of more emerging digitisation technologies leads to worse results in terms of cost performance. The conclusion that can be drawn from the study is that operational employees of automotive supply companies are facing difficulties in successfully combining real-time operational data from various sources and exploiting it for decision-making.

A second line of research has been related to analysing the configurations of Industry 4.0 technologies and the strategic intentions associated with changes in organisational competencies using a qualitative comparative analysis. This study capitalizes the outcome of a research program conducted by our Department for INAPP, the National Institute for Analysis of Public Policies. The study showed that middle-management roles are where Industry 4.0 technologies produce the most salient changes in skill profiles. Furthermore, the research also showed that digitalisation is proceeding unevenly, especially for SMEs. This is due to the skill shortage of in-house IT staff, the role of system integrators, and the difficulty of companies to internalise new digital skills and build practices with high involvement of technical and operational roles [H4.2]. On the same research program, a group of scholars in the Department has been involved in the curation of a book whose goal is to disseminate evidence and blueprints to managers and practitioners (e.g.HR specialists) on how medium-sized and large enterprises face the development of new individual skills and firm-level competencies due to adoption of Industry 4.0. The book [H4.3] will be printed and published in the spring 2023 and will be object of different initiatives of promotion and public engagement addressed to companies.

Finally, a third line of research has been related to investigating the attributes that prevent the digitalization of knowledge through a longitudinal inductive case study in the luxury fashion industry. The study (H4.4) showed that the procedural aspect of knowledge (knowing how to do something) can be codified and digitized. However, as digitalization changes the interfaces through which the physicality of reality is perceived, the creative and experiential interpretation of this knowledge remains “ineffable” and therefore not codifiable and

digitizable. In this vein, the research investigated the organizational mechanisms that enable the recombination of these "ineffable" forms of knowledge and highlights that they are underpinned by mutual adaptation through informal communication and the organization of work by teams.

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H5 Innovations for corporate sustainability

New research activities have been undertaken in 2022 on the theme of sustainable business management and sustainability-oriented innovation. A core research project on sustainability strategies in the industrial electronic industry has been based on the collaboration with one of the largest multinational mechatronic firms in the region, Bitron S.p.A. to study how sustainability-oriented innovations are influenced by supply chain dynamics, international regulation, and market signals from the largest players of the industry. For this research, we have carried out primary data collection with interviews and company visits of large multigroup enterprises in the industry (such as Siemens, STMicroelectronics, Enel, ABB) to identify the main obstacles to radical innovations. We have found (H6.1, H6.4) that the complexity of the products and a lack of formal institutional regulation has led to a disorganized approach to sustainability in the supply chain, with cascading-up of sustainability requirements from clients to suppliers, and little incentive for substantial technological investments in sustainability-oriented innovations. The working papers deriving from the study have been presented at national and international conferences (AiIG, R&D Management) and the first one with a single case study will be submitted to a special

issue of the Journal of Economic Interaction and Coordination in the beginning of 2023. Other two articles are under preparation with the analysis of the whole supply chain. This activity is coupled with other research on green supply chains and corporate sustainability in developing countries.

Moreover, the group has ongoing research on sustainability-oriented innovations in the fashion industry, with an in-depth analysis of the role of B2B "fashion engineering" companies serving the main luxury brands as a new locus of innovation for sustainability. We have mapped (H6.2) the systematic introduction of new sustainability practices and innovations within one exemplar case study of Pattern S.p.A. that gradually built internal know-how and competences regarding sustainability. In this research, we found that the commitment of the top management to a long-term vision of social and environmental responsibility is key to foster an innovative mindset throughout the company. The working paper has been presented at international conferences (Continuous Innovation Network conference specifically on the theme of "Pursuing Innovation for a Smart & Sustainable Future") and is currently under submission to the peer-reviewed journal Creativity and Innovation Management.

Lastly, we are in the initial phases of developing an analysis of circular economy and remanufacturing opportunities for the appliances industry and their scalability at the regional level. This work is based on research from the previous year on how process accumulation knowledge can enable a circular business model and will build on the collaboration of a local company, Astelav S.r.l., experimenting with a new circular business model of remanufacturing (H6.3).

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I - Algorithms and their influence on decision making processes

The 2022 activity continued focusing on various production scheduling problems always including bilevel and operating rooms scheduling problems.

The activity dedicated to production scheduling has been dedicated to various types of production schemes with special characteristics. On the one hand, flow shop problems analyzed by non-regular objective functions, such as the total core waiting time and the total core idle time are taken into consideration. This special objective functions have been studied as a follow up of the works developed in the previous years where idle and waiting times for flow shop environment have been studied as constraints. In this case idle and waiting times have been analyzed in conjunction with a common objective such as the makespan [I1].

Other research activity was dedicated to rescheduling problems. This type of problem, applicable to any static scheduling problem, provides that the list of orders can be integrated by further orders and therefore the scheduling must provide a flexible approach to integrate new orders given a maximum disruption with respect to the initial schedule [I2]. These problems are certainly of interest in view of an ever-greater flexibility and adaptability of Industry 4.0. This part of the research activities have gave rise to a broad range of problems that are actually under investigation both from a theoretical point of view as well as from the computational point of view. Another part of the activity was carried out, in continuity with previous years, on production problems characterized by the absence of idle times [I3].

The activity dedicated to the organization of workforce has been dedicated to, in continuity with the previous year, the analysis of the impact of work regulations relating to breaks in the presence of fatigue and / or boredom. This activity has important implications on work organization and workplace welfare in general. This has led to the publication of paper [I4].

The activity on exact exponential scheduling approaches and bilevel single machine scheduling approaches continued leading to publications [I5,I6].

The activity on operating rooms scheduling of elective surgeries continued in 2022. This activity is within a transdisciplinary project jointly approached with colleagues of the research Axis E on healthcare management and logistics. Part of the findings of the year 2021 for “ASL Città di Torino” were observed also for another hospital at “ASL 4”. The algorithms applied for scheduling operating rooms with a shared resource are currently being finalized in [I7]. A novel topic of research has started in this year on the well known transportation problem, one of the paradigmatic problems in graph theory. A new algorithm,

denoted “Iterated Inside-Out” [I8], has been designed. Computational testing indicates that the proposed approach strongly dominated the standard approaches for the problem including the best state of the art LP solvers such as CPLEX and GUROBI. The following other works [I9, I10, I11, I12, I13, I14] not mentioned above were also published in 2022.

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L - Algorithms for complex production systems and supply chains

The research activity of the group addressed the following issues: (1) management (at shop floor level) and analysis of production systems; (2) design and configuration of complex systems in various contexts (production, supply chain, and healthcare).

Concerning the first issue, starting from the results achieved in the previous years, the management of production systems at the shop floor level has been addressed by developing algorithms for scheduling parts on machines in specific complex contexts. Specifically, the problem of scheduling jobs in flow shops has been studied in environments where the objective functions are related to both waiting and idle time. A heuristic optimization framework (based on MILP formulations) that can solve various versions of the problem, depending on the objective the company aims to achieve, has been developed [L1]. The devised algorithms are able to minimize the core idle time (i.e., the time machines are idle waiting for the next job to produce) and the core waiting time (i.e., the time jobs wait to be processed on the next machine). These problems are common in various production system environments. For example, in many process industries (e.g., chemical or food industries), an excessively long waiting time after an operation might spoil the job and make it unusable for the next operations. Also, in those manufacturing systems where operations have to be made on pre-warmed materials, no waiting time can be allowed between warming and manufacturing phases. About idle time, instead, there are cases where resources cannot stay idle between an operation and the next one. This happens, for instance, when machines use consumables, such as paints or powders, which become unusable if the machine stays idle for too long (e.g., paint becomes dried or powder oxidizes).

In the scheduling field, the previous research on parallel batching has been continued in the current year. This problem is very common in many production environments such as the semi-conductor industry and mould manufacturing. Efficient and effective algorithms are necessary to solve such problems in the best possible way, as adequate batching and scheduling can save production capacity and better match market demand. Column generation-based algorithms have been designed to solve the parallel batching problem where batches have various maximum dimensions (e.g., maximum height, horizontal area, weight, volume), and incompatible families. For instance, in industries using Additive Manufacturing (AM), chambers can produce various parts simultaneously, either by placing products in the 2-dimensional space or by stacking products and hence using the 3-dimensional space of the chamber.

Instead, the research on the analysis of production systems addressed the evaluation of the performance measures of production systems, either by investigating the impact of characteristics of such systems or by estimating such measures for systems characterized by AM technology.

The factors influencing the variability of the inter-departure times (hence related to the throughput) of production lines has been analysed in [L3]. Although some works are present in the literature, a systematic analysis on how the distribution shape of the processing times impact on the variability of the inter-departure times has not been studied. The results of an extensive simulation campaign showed that the processing time distribution shape significantly influences the variability propagation, together with other characteristics of the system (e.g., utilization, number of stages). A thorough analysis of the theoretical and practical implications has been done, specifically referring to systems where Industry 4.0 and 5.0 paradigms are adopted.

Performance measures have also been analysed in production systems characterized by AM. Specifically, various analytical models have been developed to estimate flow time, WIP and throughput in a production system characterized by Laser Powder Bed Fusion AM technology [L4]. These estimates could be used both in operations strategy development and in technology comparison. The results showed that the level of detail of the model affects the analysis leading to quite different values of the performance measure, especially in the case of highly saturated systems.

About the second issue, following the research of the previous year, the design and configuration of production systems have been analysed. The focus has been on the problem of allocating the optimal buffer capacities to the production system (BAP), which is particularly relevant as intermediate buffers between machines allow to mitigate the effect of local variability throughout the entire production line and to reduce the propagation of blocking and starvation occurrences. An exact algorithm to solve the BAP with the aim of minimizing the total buffer costs with a minimum throughput to be achieved has been developed in [L5]. The algorithm is based on a Benders decomposition approach and it iterates between a simulation module that generates the Benders cuts and an optimization module that involves the solution of an updated MILP model. The numerical results showed that the proposed algorithm is more efficient and less time computing than the state-of-the-art.
The work proposed in [L5] uses a single MILP for optimization and performance evaluation. However, mathematical programming (MP) is not widely applied to the optimization of discrete event systems. This topic has been investigated in [L6] where a MP representation of discrete event simulation of timed Petri nets (TPN) has been presented, thus allowing to connect the two research fields. In the MP formalism, the decision variables corresponds to the transition firing time and the markings, while the constraints represents the state transition logic and temporal sequences among events. Several cases have been used to validate the equivalence between the simulation of the PN e the MP model.

The issue related to design and configuration included sustainability topics too. Specifically, the research on sustainability investigated the use of the formalization method, developed last year, for designing complex production networks with high resource efficiency levels. The method, which simultaneously considers technical, economic, and environmental performance and value creation, has been adopted in a regional project for designing production networks based on the mutual use of the waste of a company as the raw material of another. The method can help the project stakeholders (production engineers, entrepreneurs, system designers, and researchers) to design a production network by considering technical, economic, and environmental dimensions and allowed fast and customized KPI assessment [L7].

The analysis of production systems has been also extended to the whole supply chain. Specifically the design and configuration of supply chains in the fast fashion industry has

been addressed in [L8], to decide whether to include or not urban satellites in an Italian fast fashion supply chain. To this aim, an analysis on how urban satellites affect profit, based on inventory management policies and operational conditions, has been carried out. The Italian case study aims at capturing the consumers' purchasing attitudes under order-and-wait sale scenarios. Results show that urban satellites can decrease store inventory for on-shelf items, thus increasing lost demand and impacting on transportation costs. However, adding satellites allows to increase the assortment through the available retail store space, thus attracting new customers, thus increasing sales and profit. The study eventually gave managerial implications for urban satellites on store floor space usage, assortment and distribution policies.

Another complex system studied during this year is the healthcare system, following the research of the previous year. Specifically, [L9] considered the influencing drivers to direct patients to high-volume hospitals in a case study involving colon cancer patients in Piedmont. The addressed drivers are: patient characteristics, the characteristics of the closest big hospital, and territorial characteristics. The results shed light on the factors that might influence patients to choose big or small hospitals, providing some feedback on how decision-makers can drive the latter to move to big hospitals.

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1.3 Economic and Legal Perspective

M - Economic perspective

During the fifth and final year of the project, the research has been mainly directed to finalizing the studies started in the previous years as well as starting new ones. The topics covered are related to the economic implications of new digital technologies (in particular, the development of artificial intelligence, the deployment of ultra-fast broadband connections, the advance of Industry 4.0, big data, and additive manufacturing). Three are the directions of those analyses: (1) the microeconomic effects of new technologies on firms, markets, and human behavior and the potential policy interventions to sustain investments and drive social changes; (2) the implications of new digital technologies and data on markets, consumers' behavior and privacy; (3) Additive Manufacturing (AM), notably the constraint faced by firms in adopting the new technology and the effects of the adoption on firm performance.

1) As for the microeconomic effects of new technologies on firms, markets and human behavior and the potential policy interventions to sustain investment and drive social changes, several outcomes have been prepared.
The first one is a comprehensive survey of the growing literature on Artificial Intelligence [M1], published on the *Journal of Economic Surveys*, with a focus on the recent technological advances that involve machine learning applications, and on the new challenges of AI-ML for the policymakers. The survey focuses on the impact of AI on firm productivity, organization, and employment as well as on research that studies how AI affects competition and consumer behavior by exploiting newly accessible data sources, data-enabled learning and preexisting behavioral biases of human beings. On a related topic, a recent paper has focused on the role of data on market competition, pointing out how data brokers might affect market functioning. The analysis considers all the most recent theoretical literature on data economics but also the even more scant empirical evidence [M2].

Other studies, already started in the previous years of the project, have been mainly directed on studying the impact of digital infrastructure (i.e. the so called ultra-fast broadband networks) on the several economic outcomes at firm or economic level. Contributions M3, M4, M5, M6 and M7 are based on an original dataset on ultra-fast broadband deployment in Italy for the period 2013-2019 at municipal level provided within a joint project with Telecom Italia Lab, the research center of Telecom Italia Mobile (TIM Spa).

In the first paper, by complementing the data with local data on firms provided by local Chambers of Commerce, the authors study how the new fiber based infrastructure affect the establishment of local firms and its heterogeneous effects over industry, sectors, and geographical location.

In the second one, using data provided by the Ministry of Education (MIUR) on INVALSI Test, the Authors study how the use of new digital connections affect reading and math proficiency of primary school students, by focusing on the Generation Z, i.e. the cohort of children that use digital technology since a young age and are comfortable with the Internet and social media.

The third study focuses on the impact of fast connection on firm productivity. In particular, the analysis considers a unique balanced panel data for the 2013-2019 period on incorporated firms in Italy. We derive consistent firm-level TFP estimates by adopting a version of the Ackerberg et al.'s (2015) method, which also accounts for firm fixed effects. We then assess the impact of fast connections on productivity and deal with the endogeneity of fast connections by exploiting the physical distance between each municipality and the closest backbone node. Results show an overall positive impact of fast broadband on productivity. Services companies benefit the most from advanced broadband technologies, as do firms located in the North-West and South of Italy.

The last paper (M5) has been conditionally accepted, while the other two are submitted or revise and resubmitted to an international journal.

The fourth analysis focuses on the impact of fast connections on local GDP and local employment. We use micro-level panel data for the Italian municipalities over the period 2012 – 2019 and we exploit the staggered roll-out of UBB started in 2015. Through an event study approach, we find evidence of endogeneity between UBB roll-out and local labor income. To identify causal relationships, we exploit the amount of pensions to implement the estimator developed by Freyaldenhoven et al. (2019). We find that the access to UBB connections significantly increases income from self-employed workers through the increase

in their number. This effect is concentrated in urban areas with a higher level of human capital, and in municipalities at the top and bottom quartile of GDP.
In the last paper (M7), we study the role of ultra-broadband infrastructures in reducing the economic recession caused by the 2020 pandemic. We exploit the variation in GDP and employment that happened between 2019 and 2020 as a result of the Covid-19 pandemic outbreak, and we investigate whether UBB investments had an impact on economic resilience. We use micro-level data on UBB exposure in 2019 matched with municipality-level information on local GDP and employment levels based on tax declarations for the period 2019-2020. Our results show that exposure to UBB mitigates the negative effect of the pandemic on local employment. One additional year of UBB exposure increases local employment by 1.2-1.6 percentage points. The effect is stronger in areas hit more severely by the pandemic, thus confirming the role of advanced broadband infrastructures in affecting resilience from negative economic shocks.
On this topic, the research group has also continued a collaboration with other researchers at *LUISS (Rome)*, on the interplay between ultra-fast broadband and firm innovation with a specific focus on patenting and creation of innovative start-ups.
For these studies, on top with the collaboration with the Ministry of Education that is still continuing, the group has been able to sign **a new research grant** for the year 2022 with TIMLab. The research group also starts **a new collaboration** with the previous ***Italian Ministry of Innovation and Digital Transformation*** (now Department of Digital Transition at the Prime Minister Office) on the evaluation of public programs related to the Italian National Resilience Plan for the period June 2022-June 2027.

Finally, we also finalized a project started in the third year [M8] in collaboration with *Vienna University of Economics and Business (WU), the School of Business, Economics & Information Systems, University of Passau (DE)*, and *Weizenbaum Institute for the Networked Society, TU Berlin*. The analysis aims at studying the causal impact of net neutrality regulations on new high-speed (fiber-optic cable-based) infrastructure investment by Internet service providers (ISPs) and on related consumer subscription to fiber-based broadband connection services in 32 OECD countries for the period from 2003 to 2019. The paper has been recently accepted for ublication.

For what concerns the microeconomic effects of new technologies on companies, a research [M9] in collaboration with the University of Milan (DEMM), published in *Industrial and*

Corporate Change, explores the relationship between the accumulated stock of technological knowledge associated with the Fourth Industrial Revolution (4IR) and firm-level performance (labor productivity, total factor productivity, and accounting profitability). This study exploits a rich longitudinal matched patent-firm data set on firms filing 4IR-related patents at the European Patent Office (EPO). The paper detects a positive association between the stock of 4IR patents and firm-level productivity, but not profitability. Relevant heterogeneities are also detected. The effect on productivity is stronger in companies with high experience in 4IR technology development, and the same occurs in companies that have shown higher persistence in patenting 4IR technologies. Interestingly, the study highlights that the positive effect on productivity emerges for only a subset of 4IR technologies, that is, wireless technologies and artificial intelligence.

On the issue of the impact of new technologies on firms' behavior, the VisitINPS project—in collaboration with the Henley Business School, University of Reading, UK and the department of Economics of the University of Turin—has been carried on. The aim is to assess the effect of backshoring (i.e. the relocation at home of production facilities previously delocated abroad) on employment and wages at home, with an emphasis on Industry 4.0 technologies (additive manufacturing, robots and IoT) in facilitating or not backshoring and in affecting workforce composition and wage. A thorough review of the different offshoring and reshoring measures has been carried out and the different datasets for Italy (import/exports at the transaction level, firm activities and workers histories) have been prepared and soon will be merged. [M10]

2) As for the implications of new technologies and data on markets, consumers' behavior and privacy, the research in this year was focused on finalizing existing papers and start new ones. The studies that have been finalized focus both on the theoretical and empirical sides. On the theoretical side, the potential effects of regulation over the use of data by a monopolistic platform has been analyzed by means of theoretical models [M11 and M12]. Both studies explicitly consider the potential privacy loss by consumers due to their naïve behavior in using the Internet. The first analysis [M10] studies the optimal design of incentives to induce a digital platform to limit the extraction of data. The analysis shows that caps on the amount of data collected, similar to those recently implemented with Covid-19 contact tracing apps, can induce the optimal data-saving effort by the platform. The paper has been recently

accepted for publication in an international journal. The second one [M12] is a brand new analysis on how platforms, or users under a consent "Cookies" policy, choose the data disclosure level, when users are time inconsistent and provide too much personal information. Though platforms tend to disclose too much data to third parties from a society point of view, user consent policies only increase welfare if the value of data is low and the disclosure choice is easy to make. All these studies have been submitted to journals.

The new study [M13] instead investigates how the presence of a data broker (DB) who sells consumer information to downstream firms affects firm entry and consumer surplus in an oligopoly market with horizontally differentiated goods where data allow firms to price discriminate. Results show that the DB devises his data sale to minimise firm entry, limiting competition and causing consumer harm. Moreover, he only sells data to a subset of the entering firms to maximise the overall value of data. Results are robust to the introduction of a privacy cost and to the reduction of the DB's bargaining power.

On the empirical side, studies started in the third year of the project have been finalized. They focus on the impact of privacy regulation. In [M14] the authors study the impact of GDPR introduction on European website traffic. The analysis is based on an original dataset from SimilarWeb, and collects information on the amount of traffic across different channels, as well as several measures of user engagement. Results highlight heterogeneous effects across traffic channels. Web traffic coming from paid channels - such as from "Display Advertising" and "Email" - has been negatively affected by GDPR, while direct traffic to the website might have been increased as a result of GDPR enactment. In [M15] the goal is to investigate how privacy regulation affects the structure of online markets. In particular, the analysis shows that, if any, only large firms were negatively affected, while small firms experienced no significant negative effects. This suggests that privacy regulation might boost competition by leveling out the playing field for small firms. Those two studies have been realized with a collaboration with a researcher of *DG Competition – European Commission* (Bruxelles). The two papers have been recently accepted fro publication in an international journal.

In [M16] the authors develop a ML algorithm based on neural networks to study the bias of the rating systems of online platforms. In particular, the authors perform semantic analysis on the textual comments left by reviewers on the Airbnb platform. They find evidence suggesting that the host's kindness can induce a psychological bias on the rating of the listing's location left by the guest, which in principle should not be affected by the host's

behaviour. They also find that host's kindness affects not only reviewers, but also prospective guests who make their choice by reading past reviews and looking at ratings. The evidence suggests that the bias related to the host's kinder behaviour leads to significantly higher listing demand, after controlling for the overall score rating and mitigates the negative effect of an inconvenient location.

Another investigated topic where human behaviour is affected by the availability of broadband internet connection has been real estate prices and Covid pandemic. In [M17] data on real estate transactions retrieved from the Italian Minister of Finance have been used to estimate through an hedonic model the willingness to pay of real estate buyers for internet connection. Quite interestingly, results show that this willingness to pay has markedly increased during the pandemic, thereby showing how the health crisis has changed consumers' preferences. The paper has been presented in an Italian Conference and it will be soon sent for publication to an international journal.

3). As for AM adoption, the three surveys run to firms operating in the mosti important Italian goldsmith districts (Valenza, Arezzo and Vicenza) have been analyzed. The use of additive manufacturing is widespread the industry but these techniques have at present simply replaced only specific production phases of the process whereas the other phases are still run with traditional techniques. Instead, the production of jewels only through additive techniques, although technically possible through the adoption of the Selective Laser Melting (SLM) technology, is still considered too expensive and not sufficiently reliable to be implemented [M18]. In turn, this finding seems to suggest that the most important obstacle for the development of the technique is the high cost of 3D printers due to a low competition in the market.

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N - Legal perspective

Following the guidelines of this project related to the data-driven society and the new era of machines, our legal research focused on the follow-up of our main research lines in the field of law on AI, data, and 3D printing.

In the field of data security and cybersecurity, our research has benefited from the synergy with H2020 CyberSec4Europe (2019-2022), one of the four EU-funded pilot projects launched to prepare the European Cybersecurity Competence Network, whose legal unit involves the Politecnico under the coordination of Prof. Mantelero. Other synergies concern data protection and AI, due to the ongoing Relevant Research of National Interest (Progetti di ricerca di Rilevante Interesse Nazionale funded by the Italian Ministry of Education, University and Research) on “Governance of/through Big Data: Challenges for European law”, in which Prof. Mantelero is involved (consortium: Università di Roma Tre, LUMSA, Politecnico di Torino, Università del Salento and Università Commerciale "Luigi Bocconi") and the Jean Monnet Chair (Prof. Mantelero, EU Project: 101047818 – DIGIMED – ERASMUS-JMO-2021-CHAIR, 2022-25) which was granted for the first time to the Politecnico di Torino for excellence in European law studies.

In this context, our research focused on three main areas: (N.1) AI regulation, (N.2) 3D Printing and product liability, and (N.3) 3D printing and IP protection and impact of AI on corporate governance.

N.1 AI regulation

The ongoing research on AI regulation concerns the future scenario of AI regulation with a focus on human rights and the risk-based approach [N1, N2, N3]. This research has been conducted by Prof. Mantelero and is also related to his with international bodies, such as the United Nations Development Programme, and the European Commission on this topic.

The current debate on the Artificial Intelligence Act is increasingly focusing on human rights and Human Rights Impact Assessment as a key tool for future AI development. In this context, a extensive analysis of the impact of AI on both on human rights and societal issues was conducted in Prof. Mantelero's latest book [N4].

The book focuses on the impact of Artificial Intelligence (AI) on individuals and society from a legal perspective, providing a comprehensive risk-based methodological framework to address it. Building on the limitations of data protection in dealing with the challenges of AI, the author proposes an integrated approach to risk assessment that focuses on human rights and encompasses contextual social and ethical values. The core of the analysis concerns the assessment methodology and the role of experts in steering the design of AI products and services by business and public bodies in the direction of human rights and societal values. Taking into account the ongoing debate on AI regulation, the proposed assessment model also bridges the gap between risk-based provisions and their real-world implementation.

In line with one of the research tracks of the Jean Monnet Chair in Mediterranean Digital Societies and Law, the impact of the use of AI has also been investigated with regard to the use of digital technologies in humanitarian actions [N5]

Conference presentations:

• [Italy] Privacy Symposium Conference 2022, Venice, 4-7 April 2022 (Mantelero, invited speaker)

• [Belgium] 15th International Conference CPDP2022 Data Protection and privacy in transitional times, Brussels, 23-25 May 2022 (Mantelero, invited speaker)

• [Italy] State of Privacy '22, organised by the Garante per la protezione dei dati personali, Napoli, 23 September 2022 (Mantelero, invited speaker)

• [Norway] VIROS Symposium, University of Oslo, Oslo, 28 September 2022 (Mantelero, invited speaker)

• [Turkey] 44th Global Privacy Assembly, Istanbul (Mantelero, invited speaker)

• [Spain] Jornada de estudio: El futuro marco regulatorio de la Inteligencia Artificial en la Unión Europea, Universitat Oberta de Cataluny, Barcelona, 18 November 2022 (Mantelero, invited speaker)

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N.2 Product liability and 3D printing

Based on the analysis on the impact of 3D printing on the existing EU and Italian product liability framework carried out in the previous years, the research focused on the emerging role of online 3D printing platforms.

In this context, the recent EU proposal for a reform on liability for defective products does not sufficiently consider the important role that online marketplace can play in the distribution of unsafe products. The growing online circulation of 3D printing products exacerbates this issue, as it allows non-professionals products to be sold online on a large scale. This increases the risk related to the circulation of products affected by a lack of quality and safety controls, and lower the chances of obtaining compensation for damage, as prosumers do not have an adequate organisation which can bear risks arising from their activity.

Transaction platforms can therefore play a key role in the distribution chain, as they often do not act as mere intermediaries, but are in the best position to detect defective products and to remove them from their websites. In a recent publication [N6], some suggestions were provided to regulators to directly involve online marketplace actors in the liability regime. This would ensure greater protection for consumers since online marketplaces are run by companies that are more easily monitored and more likely to be able to compensate damages.

References

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N.3 3D printing and IP protection and impact of AI on corporate governance

The topic "CAD file and copyright protection" has become part of a broader research relating to the protection of the projects, of the design activity in general. Globalization, increasing technological complexity, volatility of markets and velocity of technological developments have recently led firms to shift from the traditional model of closed innovation, which relies on internal research and development of new technologies, to a model of "open innovation", which mostly depends on the exchange of knowledge with a number of external sources (other firms, universities, research institutions, self-employed professionals, and even customers) through different mechanisms (collaborative R&D, licensing, crowdsourcing, corporate venturing, etc.). In this new context, the paying public domain regime provided for engineering projects by art. 99 of the Italian Copyright Act could represent an effective innovation management tool. This regime can provide two main advantages: on the one hand, it could be able to stimulate the creativity of the individual designer, since it requires less strict requirements than those necessary for patent protection and also because the protection granted by art. 99 is substantially costless: it's only required to register the project with the Ministry of Cultural Heritage; on the other hand, like any paying public domain scheme, also this one ensures the freedom to implement the project and therefore could be able to favor the development of the competitive market and further forms of innovation. To this end, however, certain ambiguities that mark the discipline of engineering projects need to be further investigated and clarified. It is submitted that, at the end of this process, the long-time established and mainstream interpretation of Art. 99 of the Italian Copyright Act results untenable, as it betrays the original spirit of Art. 99 and determines its practical irrelevance. Nonetheless a different and more convincing interpretation is possible. The requirement of originality can be given the same meaning with which it is normally understood in copyright. In this perspective, the projects of the engineering works can therefore be considered original to the extent that they are not conditioned by the content and result from an activity of selection and combination of the various design elements among the many available. Also the

separate workstream on the interaction between AI and corporate governance is moving forward as the significant area of risk, in particular directors' liability in case of failure or mismanagement, will need to be explored in the future. In terms of publications we refer to [N7,N8].

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2 Update on project budget at December 2022

The Table below sketches in a nutshell the actual final budget compared to the overall planned budget.

PLANNED VS ACTUAL BUDGET 2018-2022

Relevant entry	Planned 2018-2022 costs/grants/positions	Actual 2018-2022 costs/grants/positions
Equipment and infrastructures	**€ 2.875.000**	**€ 2.919.051,76**
Acquisition of Associate and Assistant professors	**4 Associate Professor positions** **2 RTD-B positions** **8 RTD-A positions** **1 Technologist position**	**4 Associate Professor positions** (Mantelero, Montagna, Russo Spena, Salmi) **2 RTD-B positions** (Calignano. Salassa) **8 RTD-A positions** (Barravecchia, Battaglia, Esposito, Grinza, Pastore, Pesce, Verna and Zenezini **1 Technologist position** (Aliev)
Post-doc fellowships	**12 fellowships**	**19 fellowships** (Altavilla, Bargetto, Barravecchia, Battaglia, Castiglione, Colombari, D'Ambrosio, Gervasi, Locatello, Maculotti, Nebbia, Olivetti, Pastore, Pesce, Piscopo, Sabatino, Ulrich, Verna, Zenezini)
PhD fellowships	**6 fellowships**	**7 fellowships (+2 cofounded)** (Catalano, D'Amico, Faveto, Fontana, Gervasi, Nonnis, Rener) (Milone and Tanzi cofounded)
Visiting professors	**6 Visiting Professor positions**	**4.5 Visiting Professor positions** (T'kindt renewed for years 2020-2022 for a total of 2.5 positions, Marti Casadesus in 2021 and Klaus Armingeon in 2022)

As we can see, all the planned budget for the total expenses in equipment and infrastructures referring to the entire project has been spent in 2018-2022, actually a little bit more with additional co-financing by the Department. All foreseen Associate Professor, RTD-B

positions and RTD-A positions were filled. The foreseen technologist position was also filled. Regarding the two-years post-doc fellowships, in total 19 post-doc fellowships were assigned (some of them actually were not completed 100% as some of the post-doc grant holders eventually became recipients of an RTD-A position). As for the PhD fellowships, in total, 9 fellowships have been assigned 2 of which are co-financed by the DIGEP. Finally, 4.5 visiting professors' positions were activated. Overall, the actual budget spent was slightly superior to the planned one covered by an additional co-financing by the Department.