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

DIGEP - POLITECNICO DI TORINO

FOURTH YEAR REPORT

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This document is split into two main sections. The first section provides the research activity carried out in 2021, some relevant results/achievements and perspectives for the last year of the project. The second section sketches the relevant entries of the project budget at the end of year 2021.

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 is provided below and, then, the research main themes under the various perspectives are itemized.

1.0 General Overview

During 2021, the refurbishment of the MIND4LAB has been substantially completed and more than 90% of the related budget used, while the research activities continued quite regularly despite the COVID-19 Pandemic.

The goal of pursuing transdisciplinary projects was kept as a key indicator and several research groups were involved in joint projects: we mention here the activities on workflow balancing in production lines involving researchers of axes B/C, the activities on human-robot collaboration involving researchers of axes C/F, the activities on environmental sustainability and additive manufacturing involving researchers of axes D/G, the research on healthcare systems involving researchers of axes E/I and the activities on batch scheduling involving researchers of axes I/L.

The overall volume of 2021 project publications was substantially in line (even though slightly inferior) with the one of the previous year.

We are pleased to announce that in 2021, five colleagues were promoted at Associate Professor level: Flaviana Calignano and Gianfranco Genta who are now Associate Professors of Technologies and Processing Systems, Giulio Mangano who is now Associate Professor of Industrial Mechanical Systems Engineering, Federica Marcolin who is now Associate Professor of Design Methods for Industrial Engineering and Fabio Salassa who is now Associate Professor of Operations Research. Overall now the Department presents in total 46 tenured (Full and Associate) Professors. Also, in 2021 Dr. Davide Monni was appointed as Head of the Administrative staff substituting Dr. Alessandro Serra.

Goal of the final year of the project is to pursue the research activities of the main axes of the project with emphasis on exploiting the ones connected to the MIND4LAB while further reinforcing transdisciplinary activities.

In the remainder of this section, we present a detailed description of the progress of research activities for the year 2021 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 the year of interest are also given.

1.1 Technological Perspective

This section presents the progress during the year 2021, relating to the seven technological laboratories involved in the project, 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.

The acquisition and installation of equipment/instrumentation is being completed for all laboratories, with the exception of a limited number of items (representing about 1% of the total budget for laboratories), which are expected to be delivered and installed in very early 2022. The use of the new equipment/instrumentation was crucial for the significant progression of research activities in the year 2021.

The description of each of the seven laboratories is structured according to the following aspects:

- 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, mainly related to the scientific publications issued during 2021, 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»*".
- Plans for future research for the year 2022, which will be the last of the five years of the project.

As for previous annual reports, the research activities of the seven technological laboratories are significantly interconnected and complementary to each other, as evidenced by the numerous multidisciplinary publications issued in 2022, which involve multiple laboratories.

For example, there is a substantial connection between the research activities of laboratories D (additive production), G (sustainability) and F (quality and measurements), or between those of laboratories B (design and simulation of new processes and systems) and C (collaborative robots).

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 three previous years (i.e., 2018, 2019 and 2020).

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.

Thanks to the collaboration – started in 2020 – with the Department of Mechanics of the Politecnico di Milano (PoliMI), two experiments have been carried out during 2021. These experiments concerned the acquisition of facial and physiological data, through the adoption of depth camera and EEG (electroencephalogram) helmet. To spontaneously arouse emotions, in the first experiment participants were asked to view forty-eight images taken from the two most adopted “affective” databases (i.e., databases including images that may arouse specific emotions). In the second experiment, participants were navigated in ten virtual reality (VR) “emotional” environments, which were developed by the group to arouse their frustration, sadness, happiness, disgust, fear. The first experiment led to the acquisition of the faces of 104 subjects, the second of 30 subjects. Thanks to this data, the creation of a public facial database owned by the research group is underway, and two articles are currently in writing.

A.2 Results and dissemination

The analyses carried out on facial data using neural networks, which were trained to automatically classify basic emotions through facial expressions, show good correspondence with the emotions labelled by the participants in the post-experiment questionnaires. The implementation of a neural network for the real-time recognition of facial expressions has also been described in a patent of the research group. entitled "Methodology for the recognition of facial expressions in real time". A preliminary article on the creation of the

facial database starting from the vision of the affective databases was presented at the International Conference on Human-Computer Interaction [A1]. An invited opinion paper about the design of a dataset of affective VR environments is still in press [A2]. Two other articles related to these experiments and their results are currently under review.

A.3 Future plans

These results are the first affirmative outcome regarding the emotional viewpoint of the human-machine interaction perspective of this project, suggesting that the initial aims of the project have been partially met and now need adjustments and validations thanks to the application to specific contexts. Other studies are ongoing with obtained data, in order to answer the research questions: Does the emotion felt correspond to that shown on the face? What is the link between emotional interpretation through facial expressions and that obtained from the electrical signals of the electroencephalogram? Which tool is most reliable for detecting the emotion that the subject has really felt? Which emotions are more specific of human-computer interaction applications?

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B – Design and simulation of new processes and systems

In 2021, the research group addressed almost all the topics included in the 2020 report, with a seamless flow of activities on smart manufacturing, process monitoring/control, predictive maintenance, and technological process innovation [B1, B2].

B.1 Smart manufacturing

The availability of new research equipment and machines has enabled the experimental testing of new sustainable processes. In particular, the focus was on joining parts made in Additive Manufacturing (AM), since AM processes offer many advantages in complex shaped components, saving product weight, process time and materials. The development of

innovative, solid state, joining processes with higher energy efficiency, and/or combining different processes such as laser welding, could provide the solution to these challenging joints, extending the applicability, functionality, and life cycle range of AM products themselves.

The digital transformation has a key role in ensuring smooth joining processes, thanks to the on-line monitoring of processes. Thus, the research group faced another technological challenge to assess the reliability and repeatability of the joining processes, based on the detection of hidden anomalies in the joint. Moreover, the research group developed machine learning algorithms 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 first result of this approach was 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.). A preliminary relationship was found between the electrode degradation/wear, which was assessed by measuring the electrode contact surface, and the electrode displacement, as monitored by a non-contact sensor during welding process.

B.2 Manufacturing knowledge management

The research group operated in various technological/management sectors, consistently with the research scope to achieve the integration, improvement and innovation of the activities/resources involved in the whole product life cycle, from product development, to manufacturing, servicing and recycling. An ontology was proposed to (i) structure information from design to manufacturing and (ii) capture process anomalies and related causes at the shop floor [B3]. A platform to predict the process behaviour based on (i) real-time data and (ii) historical data was created. The latter feature guarantees a higher reliability of prediction and a more accurate and reliable estimation of future trends.

Most applications take place at the edge-computing stage, where forecast is computed in real time, emphasising the edge computing nature of the platform.

B.3 Lean production, human-machine interaction

In 2021, the research group was involved in the transfer, implementation and testing of the Lean principles and methodologies within MTS, i.e., a small-medium manufacturing company of mechanical components.

Intelligent graphic interfaces were developed by exploiting voice-assistant and/or computer-vision systems to offer efficient solutions. The research group was also involved in the improvement of *cobot* (i.e., collaborative robot) capabilities.

B.4 Personnel formation and recruitment

In 2021, the research group involved five PhD students, four of which were recruited in previous years and one recruited in November 2021.

B.5 Infrastructure

The research group completed the featured design of the robotic cell "*FabLab@Mind4Lab*" and selected the technical requirements of the devices included in the cell. Moreover, the call for economic offers was issued and most of the related orders were placed. The delivery of the first devices and equipment are expected in early 2022.

In 2021, the "*IoT Lab*" was completed and delivered in several courses to introduce future manufacturing engineers to industrial IoT concepts, communication protocols, data analytics for process monitoring, and cyber-security [B4].

B.6 Achievements

The HOME project was successfully completed on March 14, 2021. This project was funded by the Piedmont Region in the framework of "Programma Operativo Regionale POR-FESR 2014/2020", over the call for tenders of the "Fabbrica Intelligente" technological platform.

Among the outcomes of the project, a new, hierarchical, open-source model was defined, representing the factory as a machine whose resources can be monitored over time, according to the Lean paradigm. Additionally, the research group developed several Cyber Physical Systems with Edge Computing network nodes and intelligent gateways that are consistent with the factory model.

Within the framework of the CAPT'N'SEE contract – European Institute of Innovation & Technology (EIT) project) – the research group produced four educational paths (video lessons, exercises, and summary material) on lean manufacturing, cost evaluation, enterprise information systems, and artificial intelligence methods in the field of additive manufacturing. A three-day seminar was also delivered in October 2021, involving industrial experts and researchers to exchange experiences.

Finally, a three-year co-funded Ph.D. scholarship on Smart Manufacturing was awarded for the XXXVII cohort of the doctorate in Management, Production and Design, sponsored by Cassa di Risparmio di Torino and Politecnico di Torino.

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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 2021.

- *Sustainability analysis of HRC as an enabling technology of Industry 4.0*. The Collaborative Robotics Laboratory participated to an overall study [C1] on the effect of Industry 4.0 (I4.0) enabling technologies on Sustainable Development Goals (SDG). By understanding the link between the I4.0 technologies and the SDGs, researchers can better support policymakers to consider the technological advancement in updating and harmonizing policies and strategies in different sectors (i.e., education, industry, and governmental) with the SDGs. To address this gap, academic experts have investigated the influence of I4.0 technologies on the sustainability targets identified by the UN. Key I4.0 element technologies have been classified to enable a quantitative mapping with the 17 SDGs. The results indicate that the majority of the I4.0 technologies can contribute positively to achieving the UN agenda. It was also found that the effects of the technologies on individual goals can be direct and strong, as happens to collaborative robotics.

- *Providing a structured methodology to support HRC configuration choice*. Identifying the configuration that best exploits the HRC potential is not always trivial [C2]. The

previously proposed HRC evaluation framework [C3] allows to evaluate and analyse different collaborative solutions from a holistic point of view. Therefore, the goal of this research activity was to expand previous findings by presenting a methodology to support a team of experts in a structured comparison of alternative HRC configurations. The methodology incorporates a Multiple Criteria Decision Analysis (MCDA) method (i.e., ELECTRE-II) to generate a preference ranking of the considered HRC solutions. The description was supported by a real-world industrial application in the automotive field, where four alternative HRC configurations were analysed by a team of experts.

- *Experiment to explore user experience in HRC*. The effect of different configurations of a collaborative robot on user experience during an industrial collaborative task was investigated. In particular, the effects of various HRC setting factors (i.e., robot movement speed, distance from robot workspace and control of execution time) on aspects related to the perceived quality of interaction, operator's affective state, and stress were examined. One of the main novelties of this study concerns the analysis of stress through the physiological response of the user collected through a non-invasive wearable biosensor (i.e., Empatica E4). The results of the study showed that robot movement, speed and time execution/control have a significant influence on user experience. The absence of control generated more stress in the participants, as well as higher speed. However, it also emerged that higher speed is preferable in terms of perceived quality of the human-robot interaction.

- *Predictive maintenance of mobile manipulator through IoT*. The study [C4] 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.

- *Robust programming of robots*. In collaboration with Tongji University [C5], a new multidisciplinary research activity was undertaken to enable robust collaborative assembly, adapting the robot to the human partner and adjusting occasional human mistakes. The robust programming of robots is based on an application of Adversarial Reinforcement Learning to task-level robot programs. Present application of Reinforcement Learning to Robotics deals with trajectory level programming.

- *Analysis of cognitive effort required by HRC and estimate of the effect of learning rate on production throughput, in a mixed manual-automatic environment.* Task assignment methods usually rely on the fixed-mean processing times of operations, with the intent of balancing the workload assigned to operators or robots in the production line. This assignment usually neglects the variability of operator processing times. [C6] recently developed a methodology in which the operator task time is variable, according to a learning model. This methodology allows to assess the real-time task assignment adopted in the actual factory. The results show that, by including a learning model, it is possible to predict the long-term cycle time of the process more accurately. Standard scheduling strategies (e.g., first operator available, operator closest to the machine, …) were compared with learning-oriented strategies (e.g., the most skilled one, the least skilled one, …).

- *Use of smart sensors (light and heating system) distributed in laboratory facilities, for the sake of remote online diagnosis* [C7, C8]. 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). Local intelligence allows both anomaly detection and fault diagnostics, i.e., identification of the cause of the fault and choice of the corrective action. IoT allows to transfer processed information on the cloud and – on higher level of abstraction – to execute diagnostics of the entire building system. Distributed diagnostics requires the collection and harmonization of a huge number of feature data and the extraction of significant sequences by Analytics. By feeding the network with relevant data about the anomalies

extracted by local intelligent agents and by sharing the information at every level, the resulting AFDD system becomes a distributed computing application.

C.2 Enhancement of the collaborative robotics laboratory

A multi-modal collaborative Yaskawa robot was acquired in the year 2021. The robot is equipped with two laser scanner sensors that configure a virtual fence and support two operating modes: speed and separation controlled when the human beings are in a safe zone outside workspace of the robot; power and force limited (collaborative mode) when the human is in the alert and danger zone. The robot never stops unless the physical contact with the human exceeds a predetermined force or power. The robot is equipped with several tools (e.g., two-finger gripper, custom-made welding gun simulator, custom-made vacuum gripper, etc.) to reproduce most industrial assembly processes.

Another collaborative robot (OMRON) was acquired to experiment the vision empowered assembly of randomly positioned parts. The OMRON robot is equipped with an on-wrist camera that allows to detect the exact position of parts to be manipulated, using a reference tag for online calibration of the camera.

Furthermore, a motion capture system composed by eight infrared Optitrack cameras was installed in the ceiling of the robotic laboratory. With the help of a set of reflective markers, it helps tracking the motion of mobile robots and a human-held pointer, for accurate welding or gluing applications. The expenses incurred have run out the budget dedicated to the Collaborative Robotics Laboratory.

To better exploit collaborative robots, an additional (ML) workstation with PyTorch, i.e., an open-source ML library based on the Torch library and TensorFlow, was acquired. The workstation is also employed to control the motion capture system.

In order to conduct studies focusing on cognitive ergonomics in HRC, Tobii Pro Glasses 3 eye-tracking glasses were acquired with the associated Tobii Pro Lab Analyzer software license. This equipment will allow the assessment of attention level and cognitive load by monitoring eye activity and will be an integral part of subsequent human-centered studies to evaluate HRC.

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D – Additive production

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

- *Research update*. The experimental activities postponed during the COVID-19 emergency were carried on in 2021. Initially, the attention was focused on the identification of a process parameters window for the directed deposition of AISI 316L on a substrate of same material. From the perspective of the industrial application of the laser powder directed energy deposition (LP-DED) process, the parameters giving a higher energy density were explored, in order to increase the deposition rate [D1]. The effects of high-productivity process parameters on dimensional deviations, surface quality and subsurface residual stresses of the produced parts were analysed through experimental campaigns based on DoE (Design of Experiment). Even if the energy input was increased with respect to the average values found in the literature, all the tests resulted in surfaces free from significant defects, validating the possibility to extend the process parameters window to higher values [D2, D3]. More in detail, the following outcomes were obtained.

- A positive deviation, with respect to the nominal dimension, was noticed. This deviation was influenced by the energy input and especially by the travel speed, whereas the effect of the laser power was less significant.
- The surface roughness (R_a) was not significantly influenced by the analysed range of process parameters. The R_a values ranged from 10 μm to 30 μm on the lateral surfaces, while the R_a value measured on the top surfaces was higher, showing an average value of about 30 μm. The results showed the formation of periodic menisci on the surfaces, which led to a value of the kurtosis parameter of less than 3. A larger percentage of the surface was below the mean line in almost all the analysed samples. The evidence of high peaks was attributed to the presence of unmelted particles on the surface.
- The top surfaces were characterized by an initial compressive state that covered a depth below the surface, which depended on the process parameters. After the compressive region, a tensile stress was observed along the depth. The laser power and the travel speed both influenced the stress value, and a lower stress value was obtained when or a lower travel speed value or a higher laser power value was used.

On the basis of the observed results, further work is recommended to correlate the observed properties with the specific microstructure developed in the samples.

In the extensive review of state-of-art applications conducted during 2020, DED-repairing was found as one of the most promising applications [D4]. In repairing, the addition of new features on a substrate could have a significant effect on the properties of the same substrate, that should be minimized to preserve part integrity and mechanical properties. Thus, it is essential to know the heat affected zone and the depth of melt-pool that will affect the junction area between component and added material. Moreover, the underlying substrate often is not of constant size, and it could be necessary to adjust process parameters during deposition process. Since the main phenomena involved in the DED process are thermal based, the use of simulation tools can be advantageous in the early stages of analysis. In general, it can be stated that LP-DED is a complex process that implicates many interdependent mechanisms, thus prediction of temperature distribution and deposition geometry is significantly relevant for process parameters control and optimization. A review of modelling and simulation of LP-DED process, as available in the literature, was conducted [D5]. The principal modelling techniques were evaluated, highlighting which are the main phenomena that each model aims to simulate and the main advantages/challenges of modelling approaches. The major challenge in process

simulation is to develop a model that can result in knowledge at overall scale of LP-DED component and building process to apprise engineering decisions. Moreover, to be practical, the prediction model must be able to compute results in a reasonable amount of time and with reasonable computing power, maintaining sufficient accuracy in results. The objective is to keep enough physics fidelity to trust the outcome of the simulations. To this matter, an analytical model was developed, in which process parameters can vary piecewise constantly in time, which appear suitable for LP-DED production and repairing. Modelling approach is based on the solution of heat equation, coupled with an iterative feedback loop to calculate the power losses, and ensure energy and mass balance at the melt pool. The model was verified on 316L single track deposition, confirming that it is able to predict the thermal history of the component and the deposition track characteristics with good correspondence. The model resulted appropriate to simulate various scanning strategy, with piecewise constant process parameters [D6].

- *New instrumentation*. The LASERDYNE® 430 was installed in the first quarter of 2021 and it is currently operational. In order to extend the deposition possibilities to more complex geometries, a rotary-tilting table has been purchased, to be installed by the end of 2021. Moreover, the technical gas pipeline has been designed and the installation is ongoing in the laboratory. In parallel, to improve the reliability of the residual stress measurement system, a hardware upgrade was done by substituting the old strain-gauge amplifier with a new version and upgrading the software to implement the automatic detection of the hole diameter and tolerances, and to enable other back stress calculation algorithms (i.e stresses in thin walls). At this stage, the total budget for equipment is spent.
- *Future plans*. An 80% of the research activities will be concluded by the end of the 2021. Some experimental campaigns are ongoing to validate simulation tools and to characterize the mechanical behaviour of repaired components. A dedicated equipment for temperature measurements during the LP-DED process is under design and will be assembled in the beginning of 2022, allowing the coupling of simulation and experimental analysis to fine tune the prediction models and to optimize the deposition process.

D.2 Automation in metal AM production

- *Research update*. Although the advantages of AM are remarkable, some open issues still remain; one is the poor-quality surface of AM components. It rarely happens that an as-built part can be used as is and does not require further finishing processes. As regards

metal AM techniques, the laser-based powder bed processes allow near-net-shape parts to be created. Parts fabricated by electron beam-based processes usually require finishing treatments. On the other hand, the direct deposition process almost always involves a subsequent mechanical reworking of all the surfaces.

Parts can be sandblasted or shot-peened, usually by manual systems, although these techniques do not ensure a uniform and equally precise finishing on all the surfaces. In order to automatize the finishing process, massive finishing systems, such as vibratory finishing, can be used, which result in higher productivity and lower costs. Among them, isotropic superfinishing (ISF), which combines abrasive and chemical methods is a very promising solution to finish components and at the same time impart surface properties such as corrosion resistance.

The ISF process, applied to additive manufactured parts, was investigated by considering the dimensional and geometrical deviations induced by the finishing treatment, and from observations of the surface morphology [D7]. A significant reduction in surface roughness was observed on the most irregular surfaces, although the original shape was maintained. ISF process was found to be suitable for finishing additively manufactured components made of a difficult-to-cut Ti-6Al-4V alloy. The treatment is progressive and different surface quality results can be expected for different durations. The energy requirements and the costs of this finishing operation appear to be far lower than those of the other unit processes within the cradle-to-gate system boundaries. Nonetheless, the energy efficiency should be further verified, and compared with conventional machining, when much more complex geometries have to be produced. More importantly, the chemical composition of the reactants and the production of hazardous waste might affect different environmental impact categories, other than the cumulative energy demand (CED) that was assessed in this research. Therefore, further studies are needed to comprehensively address the sustainability of alternative finishing processes for additively manufactured parts.

Laser finishing (LF) and Abrasive Fluidized Bed (AFB) were also analysed since they represent cost-effective and environment-friendly alternatives for automated surface finishing [D8]. Experimental tests investigated both mechanical properties and fatigue performances on additive manufactured parts. The tests also focused on understanding the basic mechanisms involved in fatigue failures and the effects of operational parameters. X-ray tomography was used to evaluate the internal porosity to better explain the fatigue behaviour. The results demonstrated the capability of LF and AFB to improve failure performances. Moreover, LF showed a very low environmental impact compared to AFB.

- *New instrumentation*. An OTEC has been purchased and installed in late 2021 and is available for further evaluation of finishing processes on AM components. In this system, the pieces to be finished are placed in a container with abrasives and water. A rotating motion of the process container causes a relative toroidal motion between workpiece and abrasive which creates a material abrasion and thus a surface finishing on the workpiece. The water constantly flows in and out, carrying away the particles of dirt giving the workpieces a clean, corrosion-free surface finish.

D.3 Fabrication of plastic parts by photopolymerisation

Additive manufacturing (AM), or 3D printing, has attained a widespread popularity as machines and equipment necessary for fabrication have become more accessible. These manufacturing processes, however, have each their own limitations and capabilities. For instance, every machine to its own process will be able to fabricate a similar product, with different errors and accuracies. As a result, it is important that machine capabilities are known prior to utilization, so that the automated operations of the additive manufacturing systems are capable of producing a part with the desired dimensions and geometries. A benchmarking analysis was conducted through definition of a specific small reference artifact to be used for photopolymers [D9]. The dimensional accuracy was evaluated in terms of ISO IT grades (ISO 286) and standards of geometric dimensioning and tolerancing (GD&T), in order to compare machines that produced replicas of the same reference artifact using different AM processes: stereolithography (SLA), digital light processing (DLP) and PolyJet (Figure D.1).

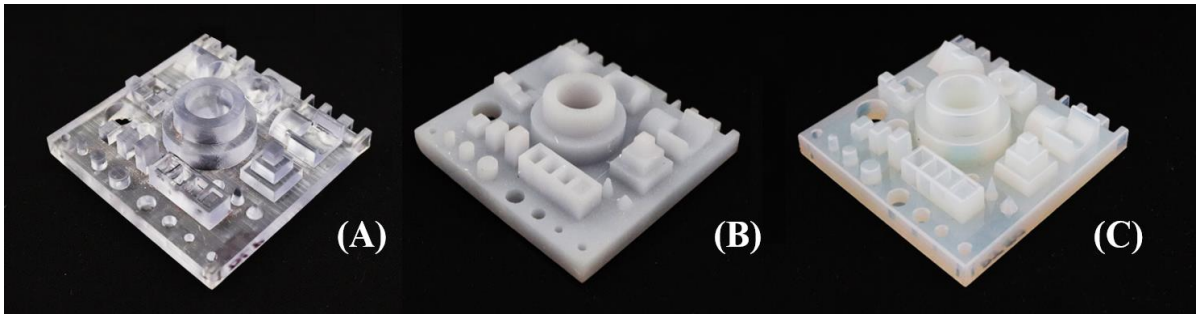

Figure D.1. Photos of the three replicas of the reference part: (A) DLP (digital light processing), (B) SLA (stereolithography), and (C) PolyJet.

For the SLA process and the PolyJet one, Antares machine by Sharebot and Objet 30 Prime machine by Stratasys were acquired within this project. After post-curing, the replicas were measured using the coordinate measuring machine (CMM) DEA Global Image which was

been refurbished and retrofitted within this project. The digital caliper Equator 300 by Renishaw was also used for comparison with CMM results.

It is expected that an additive manufacturing system's accuracy increases as ISO basic sizes increase. A general overview of the measurement results is shown in Figure D.2, where the mean dimensional accuracy for each machine is compared within a bar graph, and IT grades are set as horizontal baselines.

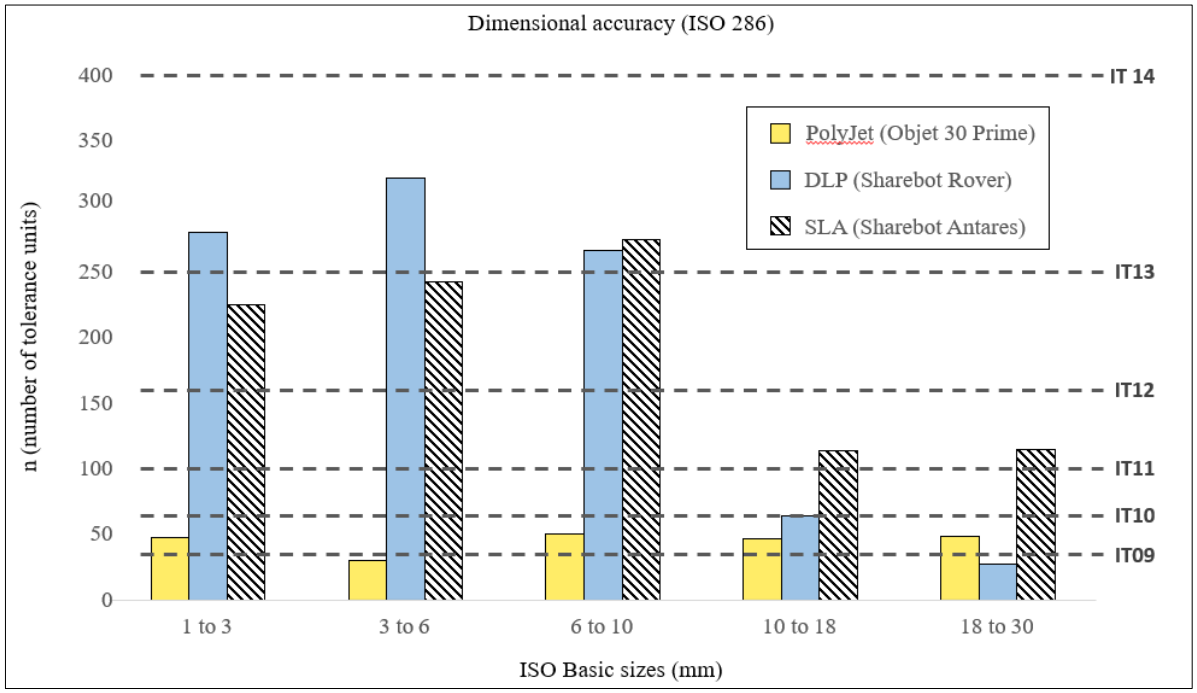

Figure D.2. Dimensional accuracy of the compared machines in terms of IT grades for different ISO basic size ranges.

Overall, the PolyJet machine performs very well in all ranges, with a consistent value for tolerances that fit with IT10 grade. Both DLP and SLA processes presented greater mean IT grades than the PolyJet replica. For smaller ranges of the ISO basic sizes, the Sharebot Rover for the DLP process presents an average tolerance grade of IT13, and shows improved performance in larger ranges. Stereolithography using Sharebot Antares can be classified as an ISO IT13 process because its accuracy fits within IT12 and IT13 grades for most ISO basic sizes.

D.4 Fabrication of ceramic parts by photopolymerisation

Additive Manufacturing (AM) encompasses a series of processes that enable the making of three-dimensional (3D) parts by adding material, layer by layer, directly from computer-based 3D model data. This alternative approach to conventional training processes is

attracting the interest of the ceramic industry, so as to create geometrically complex parts with an almost net shape without the use of expensive tools. Implementation of AM technologies with ceramic materials has been much slower than that for polymeric and metallic materials due to the difficulty in making components with good resolution and mechanical properties comparable to conventional ceramic manufacturing processes. If it considers the economic aspect, unlike conventional manufacturing processes used for ceramics such as injection molding, the overall cost of manufacturing per piece with AM technologies is independent of the geometric complexity of the component. This has brought back the attention of industries also considering that many applications of ceramic components require significantly lower production volumes than those of metals or polymers. In this context, AM is a particularly interesting and economical solution to replace injection molding for small production volumes and geometrically complex parts. The ceramic materials have been extensively studied for diverse microwave applications, and a large number of research articles have been published in this field. The constant demand for miniaturization of wireless communication devices and systems has promoted the search for lightweight, low-loss microwave materials with low sintering temperatures as well as the attraction for additive technologies. Microwave dielectric oxide ceramics play a key role in the development of lightweight circuit components for microwave and millimeter-wave frequencies. Since it is difficult to obtain an appropriate loss factor, an optimal dielectric constant, good electrical and thermal properties in a single material, polymer composites are developed to combine the advantages of ceramics and polymers. And it is precisely in this context that, thanks to the purchase of a DLP machine for ceramics and a sonicator, ceramic materials dissolved in polymer resin are being studied within two projects commissioned by ESA. There are several difficulties that are being faced such as full density without the presence of cracks, components with dimensional tolerances comparable to those required by RF applications and the metallization of ceramics also required by these applications. Tests are underway with different ceramics and different combinations of solid parts of the ceramic and subsequent post sintering process.

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E – Factory logistics

E.1 Research update

With regards to the activities planned for 2021, a physical system composed by the automated storage and retrieval system (AS/RS) and the two automated guided vehicles (AGVs), together with the Warehouse Management System (WMS) were successfully installed in the laboratory (see Figure E.1). This task has taken more time than the expected due to some issues encountered during the calibration of the AS/RS workflow. The reason behind such delays is that the operations performed by the AS/RS installed in the laboratory have represented a unique configuration and challenge for the industrial partner, namely

INCAS S.p.A. As a matter of fact, the chosen layout (see Figure E.2) combines four operations within the same installation, namely order picking, kitting, put-away and outbound. A pick-to-light system completes the AS/RS, whereby loading units are moved to the gravity flow racks for picking and kitting operations and a display shows the number of products to be picked by the operator from each loading unit (see Figure E.3).

Figure E.1. The two AGVs connected to the AS/RS.

To test the potential of the AS/RS system it was estimated the productivity of the warehouse within an e-commerce context and performed a benchmark analysis with few selected e-commerce retailers. With this regard, it was found that our laboratory does not reach the same level of productivity and thus it is not suitable, in its current configuration, for simulating the operations performed in large e-commerce distribution centres.

However, the proposed configuration allows for an increased flexibility of the automated warehouse as well as a lower space occupancy, which make the laboratory particularly suitable for several industrial sectors and applications, such as the service and spare parts industry, small mechanical parts and last-mile logistics among others.

Figure E.2. The AS/RS with the two working stations.

Figure E.3. Picking station with pick-to-light system.

In the year 2021, the simulation model built previously was integrated with the real operational parameters of the AS/RS, namely the speed and acceleration of the machine.

Moreover, the construction of the warehouse Digital Twin (DT) was started, according to the following steps.

- **Testing the feasibility of a Digital Shadow (DS)**. Within a DT architecture, the DS represents the unidirectional connection between the digital and the physical systems, thus connecting the physical system databases (e.g., orders and products database, working parameters from the programmable logic controllers (PLCs)) with the simulation model. A first implementation of the DS has been tested positively on a support simulation model and will be integrated with the one in 2022.
- **Modelling the overarching DT architecture**. In the DT architecture, the digital system integrates the simulation model with an Artificial Intelligence (AI) module. This module will be connected with the simulation model and will allow to optimize the physical system operations through the definition and calibration of different policies.
- **Parametrization of the existing simulation model**. Starting from the simulation model developed in 2020, a parametrization process has been started that aims to make the model as general as possible. In this sense, all the elements contained in the model will be more easily integrated in a DT architecture during the further development steps.

E.2 Investment

- **Hardware and software**. The installation of the factory-logistics laboratory was possible thanks to the "Dipartimento di Eccellenza" grant. So far, around 280 k€ of the total allotted of 300 k€ were committed. The remaining funds will be invested in 2022 as follows:
  - Purchase of an RFID infrastructure including a gate and 4 to 6 mobile terminals.
  - Three virtual machines for data repository and communication.
  - Acquisition of an Enterprise Resource Planning (ERP) software to manage different processes besides the ones related to the warehouse, such as managing customer orders and planning the assembly of small objects.
  - Workbenches to simulate two typical activities carried out in warehouses, namely light assembly of components and packing for the final distribution of goods.
  - Two exoskeletons to aid the picking and kitting operations and test the ergonomics of the working stations.

- **People**. The factory logistics laboratory has been integrated with the new resources planned for the year 2020:

E.3 Planned activities for 2022

Several activities are planned for 2022. First, the workflow of the picking and kitting operations will be modified to improve the productivity levels, by switching on every pick-to-light display as soon as the loading unit arrives in place. This will lower the waiting time of the operator and thus the overall process time. Second, the DT will be further developed via a full parametrization of the simulation model, a complete implementation of the DS, and the exploration of the most suitable AI and machine learning algorithms. Third, different configuration scenarios will be modelled, using the novel simulation model to test the applicability of the logistics laboratory to several industrial sectors and applications. Fourth, the logistics laboratory will be used as a teaching tool for master and bachelor students. Fifth, logistics companies will be involved in the laboratory's activities through workshops and *ad hoc* experiments.

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F – Quality and measurements

F.1 Research update

During the year 2021, the research activity on advanced methods for technological surface characterization continued. It tackled both mechanical characterization by means of non-destructive test, i.e., nano-instrumented 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.

To conclude, new research activities are focusing on the study of quality control procedures performed in human-robot collaboration systems. Quality inspection procedures are being 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.

F.2 Deliverables

- *Surface topography characterisation for tribological 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
  - Development of machine vision-aided methodology to characterise wear of hard materials and coatings
  - Development of a methodology to evaluate measurement uncertainty for machine vision-based method for low wear characterisation
- *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.*
  - Application of hardness testing to forecast residual plastic deformation of blanked aluminium sheets and validate FEM setup

- Development of bootstrap methodology to evaluate measurement uncertainty of indenter area calibration in 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.

F.3 Personnel formation and recruitment

To develop the research topics several new (human) resources were acquired and trained:

- Two post-doc researchers;
- Two Ph.D. students;
- One undergraduate student for final projects in Mechanical Engineering B.Sc. degree;
- Seven graduate students for final projects in Mechanical, Automotive and Management Engineering M.Sc. degrees.

F.4 New instrumentation

The laboratory of quality and technological surface characterisation was completed and is operational. The following items were fundamental for research activities and 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.

Latest purchased equipment includes:

- 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 operating in the definitive location, i.e., the newly built and furbished metrological cell. In 2020, a fire damaged some of the equipment in the laboratory before it could be moved to its final location. Thanks to the intervention of the insurance company and the manufacturer, most of the equipment was repaired/restored and is fully functional; an adequate warranty is expected to be returned by the end of 2021.

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);
- Department of Applied Science and Technology – DISAT (Prof P. Fino) – Politecnico di Torino (Italy);
- STAM – Science and Technology in Advanced Manufacturing Team (Prof R. Lupoi) – Trinity College, Dublin (Ireland);
- TriTech – Anton Paar, Graz (Austria);
- Department of Mechanical Engineering (Prof H.N. Hansen) – Technical University of Denmark, Kgs. Lyngby (Denmark);
- Department of Mechanical and Aerospace Engineering – DIMEAS (Prof L. Mazza and Prof A. Mura) – Politecnico di Torino (Italy);
- AGLA Power Transmission – Sant'Ambrogio di Torino (Italy);

- L.B.N. Ricerca - Sant'Ambrogio di Torino (Italy);
- Force Research Laboratory (Dr. A. Germak) – INRiM (Italy).

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

- Department of Industrial Engineering (Prof E. Savio) – University of Padova (Italy);
- Laboratoire National de Métrologie et d'essai LNE (Dr. H. Nouira) – Paris (France);
- Department of Mechanical Engineering (Prof. S. Beretta) – Politechnic of Milano (Italy);
- Engineering Digital Technology (Dr. A. Riccabone) – Avio Aero (Italy);
- Global R&I Materials (Dr. N. Li Pira) – Centro Ricerche FIAT CRF (Italy);
- Dimensional Metrology Research Laboratory (Dr. M. Zucco) – INRiM (Italy).

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G – Sustainability

The research activities of the fourth year continued on the basis of the achievements of the previous three years of project. The focus of the Sustainable Manufacturing Lab was mainly on the sustainable development of the Industry 4.0 enabling technologies [G1], in particular Additive Manufacturing (AM). The LCA (Life Cycle Assessment) based models developed during the third year where further extended. A comparative LCA method to select the best manufacturing technology between Conventional Manufacturing (CM) and Electron Beam Melting plus Finish Machining (EBM+FM) was conducted under cradle-to-gate boundaries. Three metrics, namely the Cumulative Energy Demand (CED), cost and CO_2 emissions were considered. Characterization of unit processes was done by using the recent findings in the literature, which were included in the model for both process technologies. The Specific Energy Consumption (SEC) was connected to the Material Removal Rate (MRR) and to the average Deposition Rate, respectively for machining and EBM. The main finding of this research was the description of breakeven surfaces, which separate the regions of validity between machining and EBM, as function of the Solid-to-Cavity Ratio (SCR) and the average Deposition Rate. The methodology allowed to compare the goodness of the different sets of design rules that can be chosen for EBM, due to the proper evaluation of the SEC parameter [G2]. Then, since EBM allow complex geometries to be produced with enhanced functionality but suffers from a poor surface quality, the environmental and economic sustainability of finishing processes (other than the conventional finish machining mentioned above) was studied in co-operation with the IAM@PoliTo center. The technological feasibility of the isotropic superfinishing (ISF) process, applied to Ti-6Al-4V parts produced by EBM, was investigated by considering the dimensional and geometrical deviations induced by the finishing treatment, and from observations of the surface morphology.

Environmental sustainability was analysed for all the manufacturing steps, from powder production to part fabrication, to the finishing process, and both the cumulative energy demand and material waste were accounted for. The economic impact of the whole manufacturing chain was evaluated, and the advantages of the ISF process was pointed out [G3].

Moreover, as anticipated in the third-year report, further developments included the enrichment of capability and performance assessment frameworks for manufacturing towards the circular economy. Among the well-known 6Rs of sustainable development, the impact of re-manufacturing, repair and recycling on environmental metrics was assessed. A repair procedure for mold inserts, made of H13 steel, that are used to cast aluminium cylinder heads for internal combustion engines, was studied by exploiting the Wire Arc Additive Manufacturing technology. Once the technological and quality results that are required by the strict industrial standards was verified, the life-cycle energy and carbon footprint of the repair approach were quantified and compared with those of the conventional substitution-based approach. Overall, at the end of the first life of the insert, the results highlighted that the WAAM- and repair-based approach could allow potential savings for both the performance metrics, compared with the insert being machined from a massive workpiece as a substitute, despite requiring several manufacturing steps and incoming feedstock material characterized by a high embodied energy. The environmental benefits of the proposed approach were amplified when multiple repair loops were considered, even for a lower lifespan for the repaired mold insert [G4].

Finally, aiming for a more holistic assessment at a higher system level, a maturity model for micro, small and medium enterprises (MSMEs) was proposed to assess the level of implementation of sustainability strategies and practices in this type of business. According to the literature, only a few sustainability-maturity assessment models intended for MSMEs have integrated the following three factors: environmental knowledge management, environmental strategies and good practices, and environmental management systems. The sustainability maturity model proposed for MSMEs is capable of supporting the efforts of companies in their attempts to achieve both environmental sustainability and an improvement in their production systems. The model encompasses a four-level qualitative scale and uses supervised classification algorithms to categorize companies through data analysis techniques [G5].

As for the management of the project, all the expenses planned by the research group have been carried out/committed to acquire equipment, process monitoring systems and software

for Life Cycle Assessment. The progress of the research is close to the conclusion, as scheduled. A refinement of the environmental-conscious decision-support tools (which have already been published in the last years), as well as their application to industrial case study, are expected to be achieved by the end of the project.

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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

H.1 Technological change, productivity growth 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 2021 the core of the activity has been on understanding

- the enabling factors of technology adoption in small and medium-sized enterprises in the Piedmont region [H1] - thanks to a research observative program conducted by the Department for the local Chamber of Commerce,
- the organizational processes that are crucial for converting data into actionable knowledge when companies invest in big data technologies. This paper is the outcome of a research program conducted in the electrical sector with the involvement of the two main employer associations a at the national level. More specifically, the study explores, from an absorpity capacity perspective, the organisational mechanisms through which algorithms can be exploited in converting data into knowledge for operational decision-making. Specifically, the study shows how the organisational knowledge and structures should be redesigned to take advantage of data-rich operational environments using the electricity sector as a case study. Starting from a field study involving two of the world's most important companies in the production, transmission and distribution of electricity, the study develops a new framework that theorises how the organisational mechanisms associated with absorptive capacity influence the way algorithms can be exploited to convert data into relevant knowledge for operational decision-making. The framework reveals that to convert data into relevant knowledge for operational decision-making, the involvement of line employees and liaison roles are required to introduce system-level knowledge that algorithms are able to capture less effectively. Additionally, the study shows that more formalisation is needed in operational work to ensure the quality of the data that feed such algorithms. Finally, the study provides

empirical evidence that socialisation tactics facilitate the convergence between the knowledge produced from algorithms and the experiential knowledge of line employees.

The tourism sector is a second research setting on which the Department decided to conduct its research on the technological change and competitive dynamics topic. In 2021 the most salient research outcome published consisted in a paper [2] that analysed a unique panel dataset of 276 small and medium-sized hotels over a period of three years, the research found that firms in a digitalized and online business environment develop new types of resource dependence from online intermediaries [H2]. Furthermore, the research revealed a strong interest in start-ups providing AI technological solutions for marketing automation, customer service and relationship management (i.e. chatbot for customer queries and complaint handling), which can potentially impact the effectiveness of marketing and sales' activities of the future in tourism.

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H.2 Digital revolution, digital technologies and alternative finance

This research line concerns the new technologies introduced by the digital revolution that have recently induced the rise of new methods of financing. Indeed, technological advances have enabled the emergence of new channels of entrepreneurial finance that take advantage of the fintech revolution and are based on internet platforms, often referred to as "alternative finance" (i.e. crowdfunding, peer-to-peer finance, peer-to-business finance and, more recently, initial coin offerings). While some of these channels are rapidly maturing, there remains significant uncertainty about and potential for these technological advances to affect the

markets of entrepreneurial finance. One of the crucial technologies is the blockchain. Despite the great and undoubted technological innovation linked to this technology, uncertainties and speculation on the potential scenarios still animate the industrial and scientific dialogue. The complexity of the technology itself and the difficulties in assessing its impact across the different application fields have prevented the social, industrial and scientific communities to agree upon a shared vision of future blockchain-based scenarios. Very fundamental questions are still to be answered and will represent future avenues for future research: Which blockchain-enabled applications will see the light in the next few years? Which industrial sectors will be mainly affected? How will companies react to potential industry-disruptors? How will the current societal paradigm shift? Which role will policy makers play in enhancing this new paradigm?

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H.3 Technological change, managerial tensions and technology transfer challenges and ecosystems for SMEs

This research includes a study [H7] exploring the factors that prevent companies from advancing lean corporate programmes. The importance of the study for the Italian manufacturing context is given by the fact that Italy is the second largest manufacturing country in Europe and has energy costs and flexibility in the use of labour that require companies to make advanced use of lean practices to be competitive. From a theoretical point of view, the novelty of the study lies in the fact that although there is a broad consensus on the benefits of lean programmes, little has been done to understand the human behaviours that link the implementation of lean programmes to their advancement. To bridge this gap, the study exploits a survey involving 4,700 workers in 22 Fiat Chrysler Automobiles plants. Combining unique data at plant and employee level, the study offers several recommendations for managers striving to run lean corporate programmes in competitive environments characterised by profound technological transformation in processes and products.

This research line includes also one of the most relevant issues for university managers and policy makers, which is the commercialization of Research-Based Inventions (RBI) developed by the academic faculty. Coherently with this view, researchers and practitioners have sought for instruments able to alleviate commercialization issues. In this regard, one the most recent solutions to have been proposed are Proof-of-Concept programs (PoCs). PoCs increase an RBI's Technology Readiness Level (TRL) up to a level at which it can be successfully commercialized. One of the ultimate objectives of PoCs is to fill the funding gap which characterizes the development of RBIs from the basic research stage to the commercialization stage, thus facilitating their successful launch onto the market. Despite the effort undertaken by universities and governments to stimulate the commercialization of RBIs, the results of PoCs are rather jeopardized. This points to the fact that the underlying mechanisms that favor the commercialization of RBIs may be more complex than what mere funding arguments might suggest and that the metrics used to assess the "success" of RBIs being transferred to the market may be weak. This line of research identifies he best practices on how PoCs should be structured and managed to achieve a successful commercialization of RBIs and the micro-level foundations of PoCs, namely those aspects that are related to the domain of the projects funded by these instruments and which ultimately affect the success of a PoC (H9, H8).

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H.4 Technological change, skills and work design

This research trajectory analyses how digitalization (Internet of Things, Big Data and Artificial Intelligence) is changing skills, work design and HRM practices. The empirical setting for which exploration started in 2019 and has been going on during 2020 include the

electrical sector and led to a publication on how the middle skills gaps produced by digitalization can be covered through challenge-based learning modalities. The study was based on an action research method in a research program funded and commissioned by Enel Group.

The second sub-stream of research consists in the research program done in collaboration with INAPP, the research Institute for Analysis of Public Policy in Italy. This research has started in 2020, but in 2021 it has seen the most intensive part of the empirical analysis consisting in conducting 25 case studies in 25 Italian firms across the entire country. The object of the research has been related to identify and characterize the configurations of investments in Industry 4.0 technologies in companies, exploring their impact on sills and work design and the antecedents related to management effects. This research program has finalized its outcome with the final report delivered in December 2021

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H.5 Technological change, entrepreneurship and scientific method

Rapid technological change induced by digitalization makes easier for prospect entrepreneurs to identify profitable niches of customers to be served with new products. However, the high variety of potential entrepreneurial opportunities make even harder for entrepreneurs to correctly address customer preferences, to assess the real problem to be solved and to test the viability of the proposed solution in filling their needs. For this reason, while the current technological trends make easier to collect and analyse a large amount of data and information from prospect customers, it is crucial to strengthen the capability of entrepreneurs to extract the correct information from the set of data gathered in order to correctly take their decisions. This research line analyses how the decision-making process of early-stage entrepreneurs can be informed and improved by the use of the scientific method. According to this approach, entrepreneurs select information and evaluate the potential of their business ideas through the use of a method similar to that used by researchers when

developing scientific theories. In this project, in particular, the specific aim is to study the importance of the scientific approach to decision-making in comparison to other methods commonly used by entrepreneurs when taking decisions (e.g. the effectual approach) (H12). In order to test these research questions, the Randomized Control Trial (RCT) presented in the report in the last year has been taking close its end. The RCT, involving about 500 early-stage start-ups from Italy, has been concluded and participants to the pre-acceleration program have participated to twelve workshops and seminars in order to continue their training.

Although the early results on such studies are showing the effectiveness of the scientific method in fostering early recognition of entrepreneurs about the feasibility and prospect success of their entrepreneurial idea, less is known about the cost of their experimental process. For this reason, in this year, a new line of research has been opened with this aim [H13]. In this research, exploiting the data collected in the previous RCTs launched at Polito and Bocconi University, the research team has analysed whether scientific entrepreneurs spend more than other entrepreneurs to assess the effectiveness of their entrepreneurial idea. Moreover, they tested also whether such cost of experimentation is recovered more quickly by them or by non-scientific entrepreneurs. Results have shown that scientific entrepreneurs spend more pre-entry (i.e., before selling their product on the market) and exhibit different spending behaviour before and after entry. Based on these findings, it is possible to argue that scientific entrepreneurs learn differently and that their investment in experiments is a key determinant of subsequent choices. The model and results emerging form this study provides an initial answer to the crucial question of how much and when entrepreneurs should invest in experiments.

Finally, in this last year, a new RCT aiming to target more advanced start-ups has been designed. This RCT aims to reach start-ups already operating on the market in order to train a group of them with the scientific method with specific business area as operations, finance and human capital management. The RCT main purpose of this RCT is to test the applicability and effectiveness of the scientific method to later-stage start-ups. The RCT will take place starting from May 2022.

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I - Algorithms and their influence on decision making processes

The 2021 activity continued focusing on various production scheduling problems but considering also bi-level and operating rooms scheduling problems and problems related to the organization of workforce.

The activity dedicated to production scheduling has embraced various types of production schemes with special characteristics. On the one hand, parallel batch scheduling problems are taken into consideration, which can be found, for example, in additive production systems [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 an adaptation 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. Finally, part of the activity was carried out, in continuity with previous years, on production problems characterized by the absence of idle times [I3]. Also, the activity on the so-called two-machine flow shop problem with three operations and as objective function the minimization of the makespan was completed and published [I4}.

The activity dedicated to the organization of workforce was developed in the analysis of problems relating both to the automatic generation of staff shifts, in continuity with the previous year, and to the analysis of the impact of work regulations relating to breaks in the presence of fatigue and / or boredom. This activity has led to the preparation and submission of a paper [I5]. Future activity dedicated to this area will be devoted to further understand if the use of quantitative approaches, such as combinatorial optimization methods, may clarify whether actual work regulations (in specific working systems) may need be revised or updated with the goal of fairness in shift scheduling possibly in collaboration with the law and policy making areas of DIGEP.

The research activity on bilevel scheduling in single machine continued in 2021 [I6] while an extension on bilevel transportation led to a published paper on a highly cited international journal [I7]. A new line of research started on the intersection between Algorithmic Game Theory and Integer Programming, see [I8].

The activity on operating rooms scheduling of elective surgeries continued in 2021. This activity is within a transdisciplinary project jointly approached with colleagues of the research Axis E on healthcare management and logistics. This year, several monthly assignments of the operating rooms to specialties were provided by DIGEP, Polito to "ASL Città di Torino". Besides, the problem of scheduling operating rooms with a shared resource was tackled. In this problem, the aim is to determine a daily schedule for a set of operating rooms where each operating room is associated with a surgical specialty and a set of surgical interventions are ready to to be processed performed for the considered day. Further, a subset of the interventions requires the use of a shared resource among the operating rooms so that no two interventions using that shared resource can be processed simultaneously [I9]. The following other works [I10, I11, I12] not mentioned above were also published in 2021.

In terms of dissemination, the organization of the next MAPSP (Models and Algorithms for Planning and Scheduling Problems) Conference is proceeding and calls for papers were launched in November, see https://mapsp2022.polito.it . The Conference is expected to take place at Oropa Sanctuary (BI), Italy, from June 12 till June 17, 2022.

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L - Algorithms for complex production systems and supply chains

The research activity of the group focused (1) on the design of algorithms to efficiently and effectively solve large MILP models to deal with system configuration and management, especially at shop floor level, and (2) deepen the study of sustainability issues.

Starting from the results achieved in the buffer allocation problem in the previous years, research activity (1) aimed at solving the Server Allocation Problem (SAP) by using a meta-heuristic approach. A more general version of the SAP was addressed, where the production system is a hybrid flow line with non-identical machines, which has never been addressed in the SAP literature so far. Specifically, a Variable Neighbourhood Search was implemented to solve the problem, which was proved to be very efficient from an extensive numerical campaign [L1].

In the research on production systems, also techniques to implement digital twins in real cases have been studied. In fact, manufacturing companies need to improve their production monitoring and prediction to be more flexible and re-configurable. The digitization of the manufacturing environment becomes, in this context, a very critical issue. The research in this field has then be devoted to developing digital twins in this complex environment. Discrete event simulation models, connected in real-time with their real system counterparts, have been developed and analysed in two case studies [L2].

Considering more standard production planning problems, such as scheduling problems, algorithms based on column generation techniques have been developed to address a parallel-batch problem, in which the available jobs are partitioned into batches and then batches are scheduled on the production system. This problem is very common in many production

environments such as semi-conductor industry and mould manufacturing. Efficient and effective algorithms are necessary to solve such problems in the best possible way, as an adequate batching and scheduling can save production capacity and better match market demand [L3].

In the scheduling field, also the open shop with sequence dependent setups has been studied. Such problem is very different from standard open shop problems, which are already very difficult due to the lack of given processing routes. This increases the number of feasible solutions, and thus the solution complexity. For the problem with sequence dependent setups, the literature is very scarce and only a few meta-heuristics have been proposed. The study of the research group, instead, focused on matheuristic algorithms based on variable fixing of the continuous relaxation of the mixed integer model, and the preliminary results showed to be very promising [L4].

In the research line focused on algorithms applied to complex systems, the planning of health care systems has also been considered. [L5] specifically develops an approach to plan the number of surgical interventions that a facility must perform to assure a low adjusted mortality rate. The approach explicitly considers the existing interaction among patients' choices and decision makers' planning decisions, which has hardly been studied in the field. The proposed approach has been applied to a case study on Italian colon cancer interventions performed in 2014.

About the research on sustainability issues (2), the simultaneous assessment of technical, economic and environmental performance and value creation of the production systems has been investigated. The definition of a new formalization method, data-driven oriented according to the Industry 4.0 and 5.0 paradigms, focused on reducing redundancy in data collection and processing activities, and partial information, increasing data consistency among the several performance dimensions, avoiding hidden risks and opportunities [L6].

Next year research will focus on various research fields. Starting from the results on simulation-optimization models, next year research will focus on developing an automated generation of mathematical programming representation for general discrete event simulation models, to help the study of complex problems using a common framework at least for a class of production design and or planning problems. In the field of scheduling, the problem of integrating the scheduling of jobs in the machines and transporting jobs among machines will be studied and methods to solve it will be developed to address the lack of efficient procedures in this field. The open shop scheduling problem will also be deepened to develop algorithms based on disjunctive graph approaches. Moreover, the extension of the so-called

price of fairness, very common in health care systems, to production systems will be studied. Within the problems of buffer and resource allocation, various optimal solutions can be found by optimizing different performance measures, and addressing the price of fairness implies comparing these different optima. This comparison might be useful to consider together various performance indicators that production systems rely on nowadays.

Another topic, very relevant for production systems, is the variability of the performance measures such as the throughout, which is the most used to evaluate a system performance. Although some works are present in the literature, a systematic analysis on how characteristics of the arrival process and processing times (e.g., skewness, type of distribution, etc.) impact on the variability of the throughput has not been studied. The next year research will also be devoted to such an issue.

Moreover, considering the simultaneous assessment of techno-economic-environmental performance in manufacturing systems, the adoption of the data-driven formalization method will be investigated in the context of automatic detection of changes to update representation of the system. The aim is to define an architecture to support both multidimensional production monitoring and system model update.

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1.3 Economic and Legal Perspective

M - Economic perspective

During the fourth 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: (M.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; (M.2) the implications of new digital technologies and data on markets, consumers' behavior and privacy; (M.3) Additive Manufacturing (AM), notably the constraint faced by firms in adopting the new technology and the effects of the adoption on firm performance .

M.1 Microeconomic effects of new technologies on firms, markets, and human behavior

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], recently accepted 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 third year 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 and M6 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.

All these three studies are in the process of Journal revision or resubmission.

Finally, the fourth analysis focuses on the impact of fast connections on local GDP and local employment. Preliminary results show some positive effect of fast connections on specific areas of the country on GDP and employment, and in particular in areas in the North and South of Italy characterized by a high (top quartile) level of GDP at the beginning of the observation period (2012).

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 2021 with TIMLab. The research group also starts a new collaboration with the Italian Ministry of Innovation and Digital Transformation on the evaluation of public programs related to the Italian National Resilience Plan.

Finally, we also finalized a project started in the third year [M7] 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.

For what concerns the microeconomic effects of new technologies on companies, a research [M8] 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 new VisitINPS project—in collaboration with the Henley Business School, University of Reading, UK and the department of Economics of the University of Turin—has started in November 2021. The aim is to use individual-level data about the population of workers in Italy and to assess the effect of backshoring (i.e. the relocation at home of production facilities previously delocated abroad) on employment and wages at home. By using transaction-level data on inputs purchases, the role of Industry 4.0 technologies (additive manufacturing, robots and IoT) in facilitating or not backshoring and in affecting workforce composition and wage will be assessed. [M9]

M.2 Implications of new technologies and data on markets, consumers' behavior and privacy

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 [M10 and M11]. Both studies explicitly consider the potential privacy loss by consumers due to their naïve behavior in using the Internet. The first analysis [M9] 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 second one [M11] 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 [M12] 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 [M13] 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 [M14] 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).

In [M15] 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 behavior can induce a psychological bias on the rating left by the guest. Moreover, after controlling for the rating, a kinder host's attitude is associated with significantly higher demand for the listing.

Another investigated topic where human behaviour is affected by the availability of broadband internet connection has been real estate prices and Covid pandemic. In [M16] 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.

M.3 Additive Manufacturing (AM)

As for AM adoption, two new surveys in the goldsmith industry have been run, one in the Valenza and the other in the Arezzo industrial districts. Results have confirmed those obtained in the Vicenza disctrict: the use of additive manufacturing is widespread the industry. However, additive manufacturing techniques have at present simply replaced some 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 [M17]. 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,[1] whose legal unit involves the Politecnico under the coordination of Prof. Mantelero. Another synergy 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").

In this context, our research focused on four main areas: (N.1) AI regulation, (N.2) data security and cybersecurity, (N.3) 3D Printing and product liability, and (N.4) 3D printing and IP protection and impact of AI on corporate governance.

The Covid pandemic had a negative impact on national and international cooperation, limiting the possibilities for dissemination and interaction with other partners. In addition, the increased effort required to migrate to distance learning had a strong impact on the legal research team, due to the limit number of people in our unit and the comparatively lumber number of courses.

N.1 AI regulation

The ongoing research on AI regulation concerns the future scenario of international human rights-based regulation of AI. This research has been conducted by Prof. Mantelero and is also related to his appointment as the scientific expert on AI and data protection of the Council of Europe and the work of the Ad hoc Committee on Artificial Intelligence.

The current European debate on Artificial Intelligence is increasingly focusing on human rights and Human Rights Impact Assessment as a key tool for future AI regulation and development. Against this background, through the analysis of more than 700 decisions and documents of the data protection authorities of six countries, we have investigated the role of human rights in underpinning the decisions in the field of data use. Based on this empirical analysis, we presented a methodology and a model for a Human Rights Impact Assessment (HRIA). The methodology and related assessment model are focused on AI applications, whose nature and scale require a proper contextualisation of HRIA. Moreover, the proposed models provide a more measurable approach to risk assessment which is consistent with the regulatory proposals centred on risk thresholds.

[1] https://ec.europa.eu/digital-single-market/en/news/four-eu-pilot-projects-launched-prepare-european-cybersecurity-competence-network.

The proposed methodology is tested in concrete case-studies to prove its feasibility and effectiveness. The overall goal is to respond to the growing interest in HRIA, moving from a mere theoretical debate to a concrete and context-specific implementation in the field of data-intensive applications based on AI. [N1]

Given the interest of the EU legislator on AI and the intention to broaden the focus of the regulatory initiative to include liability issues, our ongoing research on AI in the field of Private Law has recently expanded its scope to include civil liability, and project resources were allocated to a new research fellow position (assegnista di ricerca) for this new track.

Conference presentations:

- [Poland] IGF2021, The challenges of AI Human Rights Impact Assessments, Katowice, 10 December 2021 (Mantelero, invited speaker)
- [France] Symposium Human Rights in the Digital Sphere organised by Council of Europe, Permanent Observer of Japan to the Council of Europe, and Rene Cassin Foundation, Strasbourg, 18 October 2021 (Mantelero, invited speaker)
- [Austria] Fundamental Rights Forum 2021organised by the European Union Agency for Fundamental Rights, Vienna, 10 October 2021 (Mantelero, invited speaker)
- [Italy] Pan-European dialogue on Internet governance (EuroDIG), Triste, 29 June 2021 (Mantelero, invited speaker)
- [Belgium] Generalitat de Catalunya – Escola d'Administració Pública de Catalunya, Autoritat Catalana de Protecció de Dades, Barcelona, 24 February 2021 (Mantelero, invited speaker)

References

[N1] Mantelero, A and Esposito, MS (2021) An evidence-based methodology for human rights impact assessment (HRIA) in the development of AI data-intensive systems, 41 Computer Law & Security Review, 105561, https://doi.org/10.1016/j.clsr.2021.105561

N.2 Data security and cybersecurity

In this interdisciplinary field, the research carried out in 2021 is a follow-up of the results achieved in the H2020 research project "CyberSec4Europe" (Cyber Security Network of Competence Centres for Europe), where prof. Mantelero is task leader (Legal and regulatory requirements). Focusing on the common principles and procedural approaches related to specific cybersecurity and data security technologies, we have further elaborated the analysis

of the interplay between data protection and cybersecurity in a new publication [N2] and conference presentations.

Conference presentations:

- [Online] 2021 World Technology Law Conference, 2 June 2021 (Mantelero, invited speaker)
- [Belgium] CPDP2021 Conference, Cybersecurity for Europe: Fostering rights through technology, panel organised by CyberSec4Europe 27-29 January 2021 (Mantelero, invited speaker)

References

[N2] Mantelero, A and Vaciago, G (2022) Reconciling Data Protection and Cybersecurity: An Operational Approach for Business Sector. In Senigaglia et al. (eds) Privacy and Data Protection in Software Services (Springer Nature)

N.3 Product liability and 3D printing

This research activity focused on the impact of 3D printing on the existing European and Italian product liability legal framework.

Product liability regimes traditionally target producers due to their role in making products safer and in an efficient allocation of compensation costs. However, 3D printing introduces substantial changes in the traditional supply chain, enabling non-professionals to become manufacturers and sellers of products (so-called ‘prosumers’). Moreover, in the 3D printing context, the production chain is no longer linear, as not only consumers but also online platforms can play an important role, as well as fab-labs and 3D printing services. In addition, existing product liability rules applies only to movables, which are traditionally considered as tangible goods (with the exception of electricity). Consequently, where damage is due to a defective digital good, such as CAD files used in 3D printing production, product liability rules do not apply.

These issues urge therefore us to rethink traditional liability dynamics for an optimal allocation of damage costs.

Following the analysis in previous years, the research activity in the third year has highlighted

the main issues that should be considered by the European legislator and provided some suggestions for a reform on product liability including more effective protection.

In this context, we highlighted how and to what extend it is possible to expand product liability to new emerging players in 3D Printing, and the limits of such extension with regard to non-professional producers.

Our research also paid particularly attention to the emerging role of online 3D printing platforms. This is because these online platforms can play a central role in the distribution of 3D products and are potentially in the best position to detect defective products and to remove them from their websites. Moreover, online marketplaces often do not act as mere intermediaries but intervene in the supply chain in many ways. However, according to the existing regulatory framework transaction platforms are not liable for damages.

In this scenario, we highlighted some tools to involve platforms in products safety issues and to also include them in the product liability regime [N3, N4].

Conference presentation:
[Online], Bileta Conference 2021, (Re-)constituting the critical in an age of digital and pandemic, 16 April 2021 (Esposito speaker)

References

[N3] Esposito, MS La responsabilità per danno da prodotto difettoso nel contesto delle piattaforme di marketplace, anche alla luce delle implicazioni derivanti dalla stampa 3D (forthcoming).

[N4] Esposito, MS Product liability in the context of 3D printing and the role of online platforms (forthcoming)

N.4 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. Also the separate research stream on the interaction between AI and corporate governance of large and medium size corporations is currently under further development: data-driven decisions supplemented with AI have shown to improve capital allocation and to increase the accountability of management decisions. There is a significant area of risk to explore from a legal perspective, in particular liability profiles in case of failure or mismanagement (which shall be explored in the coming years).

References

[N5] R. Rivaro, Engineering projects in the copyright system, in AIDA 2021, forthcoming

2 Update on project budget at December 2021

The Table below sketches in a nutshell the actual 2018-2021 budget compared to the overall planned budget.

PLANNED VS ACTUAL BUDGET 2018-2020

Relevant entry	**Planned 2018-2022 costs/grants/positions**	**Actual 2018-2021 costs/grants/positions**
Equipment and infrastructures	**€ 2.875.000**	**€ 2.597.088,36**
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) **7 RTD-A positions filled** (Barravecchia, Battaglia, Esposito, Grinza, Pastore, Pesce, Zenezini – Barravecchia, Battaglia and Zenezini were previously post-doc grant holders) **1 Technologist position filled** (Aliev) **1 RTD-A position announced,** (to be filled by summer 2022)
Post-doc fellowships	**12 fellowships**	**14 fellowships** (Altavilla, Bargetto, Barravecchia, Battaglia, D'Ambrosio, Maculotti, Nebbia, 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**	**3.5 Visiting Professor positions** (T'kindt renewed for years 2020-2022 for a total of 2.5 positions, Marti Casadesus visited DIGEP in 2021) **1 additional Visiting Professor position planned for 2022**

As we can see, approximately 90% of the planned budget for the total expenses in equipment and infrastructures referring to the entire project has been spent in 2018-2021. All foreseen associate professor positions and RTD-B positions have been filled; 7 RTD-A positions were filled until now and another one has been announced to be filled by mid june 2022 so as to cover the planned 8 positions. The foreseen technologist position has been filled in December 2021. Regarding the two-years post-doc fellowships, in total 14 post-doc fellowships have been assigned until now (two of the post-doc grant holders eventually became recipients in 2021 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, 3.5 visiting professors' positions have been activated and one visiting professor position has been planned for the year 2022 of a total of 6 positions planned in the project. Overall, the actual budget is fully in line with the planned one where a small part of the budget initially foreseen for IT equipment (approx. 200k euros) is being redirected in order to further increase post-doc and PhD fellowships to start in 2022 and to cover the international advisory board financial support.