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

DIGEP - POLITECNICO DI TORINO

THIRD YEAR REPORT

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This document is split into three main sections. The first section provides the research activity carried out in 2020 and some relevant results/achievements. The second section sketches the relevant entries of the project budget at the end of year 2020. The third section provides indications on the planned activity for the 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 general overview of the Department Research activity is provided below and, then, the research main themes under the various perspectives are itemized.

1.0 General Overview

The 2020 activity has obviously been affected by the COVID-19 Pandemic. This was particularly noticeable for all activities concerning laboratories, due to several lockdown periods during the year. For example, the completion of the refurbishment of the MIND4LAB was inevitably delayed by a few months.
Still, DIGEP was able to continue all research activities and the following of this document clearly depicts this. Besides, the pandemic stimulated several "unprecedented" research activities, see, for instance, research items H_2, H_3 and I.

We are pleased to announce that in 2020, three notable recruits were listed at DIGEP: Riccardo Calcagno, who is a Full Professor of Finance and Financial Intermediation coming from the Business School of Lyon (France), Guido Perboli, who is an Associate Professor of Operations Research coming from the Department of Control and Computer Engineering of Politecnico di Torino, and Stefano Sacchi, who is a Full Professor of Political Science coming from the Luiss University, Rome, Italy. The research activities of these colleagues perfectly fit with one of the main goals of the Department, that is of increasing its multidisciplinarity, in terms of research. Their research activity will be listed from 2021 on within this project.

Having passed the first half of the project, we provide below a SWOT analysis of DIGEP and related implications for the considered project.

Strengths	Opportunities
• **[S1] High diversity and complementarity of the scientific areas in the Department. This complementarity is directly functional to the analysis of emerging issues on industrial change and the related impacts on technologies, business models and related markets.** • **[S2] Close connection of the Department with the "Engineering and Management" School ("Collegio"), which in recent years is seeing a high growth in the number of students enrolled (first degree course in terms of number in Politecnico di Torino) and excellent results in terms of employability of the graduated students on the labour market (according to Almalaurea and the QS international ranking).** • **[S3] The Department plays a crucial role of service to the Politecnico di Torino, due to specific scientific expertise, in the areas of organization, technology transfer, entrepreneurship and relations with the business world.** • **[S4] For several years, the Department has demonstrated the ability to experiment new innovative teaching and pedagogy approaches in all the educational levels and programs present at Politecnico di Torino.**	• **[O1] The "Dipartimenti d'Eccellenza" Miur project has given significant funding for laboratories, tenured track positions and post-doc research fellows.** • **[O2] Companies see an increasing availability of research funds, financed through competitive calls for high Technological Readiness Level (TRL), which require competencies and technology assets present in the Department, since it is oriented towards innovation and industrial impact.** • **[O3] The managerial and technological gap of SMEs in the area generates a potentially high demand for services that the Department can offer within all three missions.**
Weaknesses	**Threats**
• [W1] The internal complementarity between the disciplinary areas is partly unexpressed and underexploited, due to a limited capacity for interdisciplinary collaboration. • [W2] The department is undersized and below the critical mass needed to balance (i) teaching, especially of an innovative type, (ii) being effective in the international competition for the procurement of research funds, (iii) attracting young researchers from outside, and (iv) starting growth plans for the staff. • [W3] Reduced number of personnel for running laboratory operations and administrative roles specialized on project management and administration of complex projects .	• [T1] More and more competitive funding at the EU level will be based on collaborative research projects between firms and universities. Those departments of Politecnico di Torino, which are more adaptive and better positioned on this dimension, can see a faster growth than DIGEP's. • [T2] Other departments can regard DIGEP's competencies as commodities that can be easily imitated and reproduced inside their area. This can lead to a reduced involvement of DIGEP on trans-departmental research projects and an increase in competition on the market of education.

SWOT matrix issued from the Strategic Plan of DIGEP, for 2021-2025.

The above SWOT analysis suggests leveraging our project through multiple avenues, such as

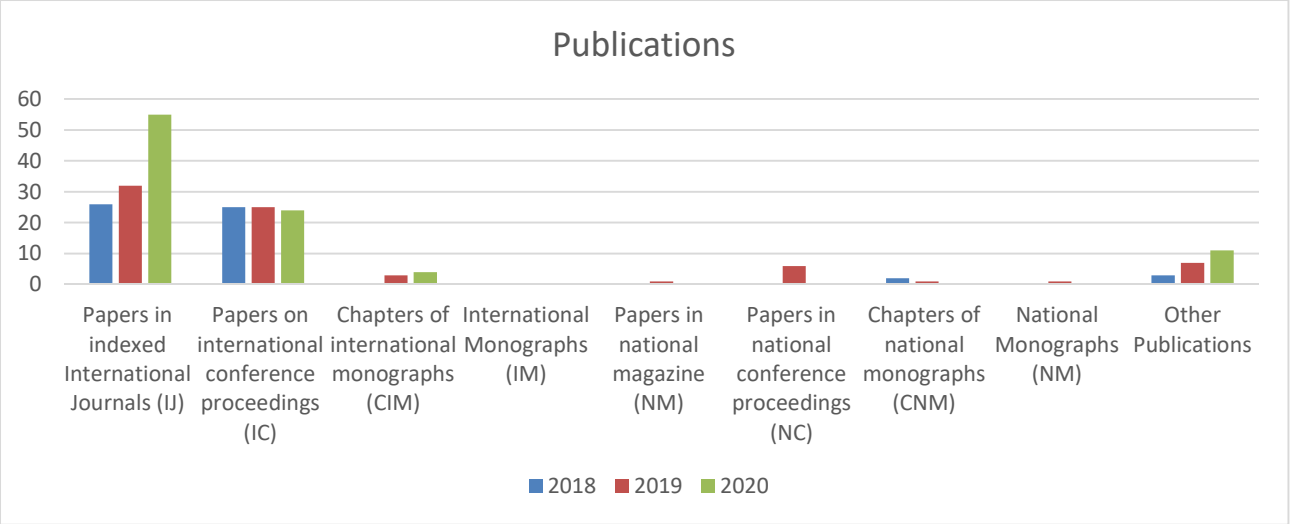
a. increasing the capability of multidisciplinary research projects that involve assets of the new laboratories created through the funding; preferably such projects must be developed on competitive tenders and calls at the regional, national and EU level;
b. increasing firm-university collaborative research projects that involve assets of the new laboratories created through the funding;
c. investing in further personnel that can run laboratory operations and that can have capabilities to manage research projects (mitigation of W3); funds raised through the above-described type of research projects can generate the resources to bear the labour costs of technologies;
d. given S4, encouraging the use of laboratories for teaching (M.Sc. programs, executive education, training programs for professionals) in initiative with a high level of innovativeness in the pedagogy (e.g. Fablab, challenge-based learning and other type of experiential learning);
e. adopting a system of metrics to assess the impact generated by laboratories on the three university missions on a year-basis;
f. creating incentives (e.g. co-funding) and an assessment system through which research groups and laboratories can be active on each of the above described trajectories and are strongly encouraged to work together.

Indeed, some research groups already exploited the last-mentioned item and conducted preliminary steps towards multidisciplinary projects. As an example, the research and investments made in the three years of the project have allowed several researchers to cross the typical perimeter of Engineering and – more generally – of hard sciences, establishing interesting collaborative networks with high-profile researchers in the humanities, to investigate frontier research topics concerning human-robot collaboration.

Worthy of note is the recent involvement of several DIGEP researchers representing the research axes "C - Collaborative robots" and "F - Quality and measurements" – in a collaborative network including the Affective and Social Neuroscience research group of “Università Cattolica” in Milan, the Evolutionary Algorithms and Machine Learning research group of the University of Parma, the Clinical Psychology research group of the University of Turin, specialised in Clinical Psychology and the Machine Learning and Artificial Intelligence research group of the Department of Control and Computer Engineering at Politecnico di Torino. This research team has just produced a research proposal in the framework of the so-called "Projects of Major National Interest" (PRIN), entitled "Empathically enhanced robot for the collaboration with HUmans in MANufacturing (e-HU-MAN)" and coordinated by Luca Mastrogiacomo.

Similarly, several DIGEP researchers representing the research axes of "F – Quality and measurements" and "I - Algorithms and their influence on decision making processes " – were involved in a collaborative network, including the Precision Manufacturing research group of the University of Padua, the Materials Science and Technology research group of Roma 3 University and the Artificial Intelligence research group of the University of Brescia. This research team has just produced a research proposal in the framework of the so-called "Projects of Major National Interest" (PRIN), entitled "Zero-Defect Manufacturing: development of a Cyber-Physical System framework integrating Artificial Intelligence models for in-line optimization of quality control and product defect reduction –AI.M.4.0-Defect-MAN" and coordinated by Maurizio Galetto. Further synergies between distinct research groups of the Department have also been reinforced.

The bar-chart below shows the evolution of the project publications (classified by type) for the years 2018, 2019, and 2020.



In the remainder of this section, we present a detailed description of the progress of research activities for the year 2020 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 2020, 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.

For each laboratory, we can identify two main types of activities: (1) acquisition and installation of research equipment/instrumentation and (2) research, both theoretical and experimental.

The acquisition and installation of equipment/instrumentation – which had often been bureaucratically cumbersome, due to the relatively high cost of the assets involved – is being completed for most of the laboratories. With just a few exceptions, the overall progress of these activities can be estimated to be between 70% and 80%.

Research also progressed significantly, despite (i) the inherent difficulties of 2020 and (ii) the unavailability of part of the research equipment and instrumentation. In addition, the refurbishment of the Mind4Lab premises was delayed by about six months (until October 2020), due to the ongoing pandemic.
The description of each of the seven laboratories is structured in order to address the following aspects:

- Progress of the acquisition/installation process of research equipment/instrumentation;
- Progress of research, especially that which was accomplished using the resources acquired during the project (e.g., instrumentation, personnel, software, etc.);
- "Achievements" (i.e. scientific honours and awards) linked to research activities related to the project;
- Scientific publications issued during 2020, concerning research activities that are relevant to the project. Each publication is acknowledged with the wording: "*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»".

It is worth remarking that the research activities of the seven technological laboratories are significantly interconnected and complementary to each other. One proof of this is represented by the multidisciplinary publications produced in 2020, involving 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 two previous years (i.e., 2018 and 2019).

A – 3D modelling and simulation

Regarding human-machine interaction issues, the research activities carried out in 2020 concern the adoption of 3D modelling, digitization, simulation and advanced digital visualization.

The analysis of three-dimensional facial data to quantify the user's engagement via facial expression recognition undergone in the past two years of research has been deepened with comparative studies, thanks to results obtained via questionnaires. Also, the adoption of tailored neural networks for the categorization of facial expressions has improved the recognition rates [A1, A2]. Thus, the Emotional Design approach for designing innovative products, in a product life cycle logic, is successful for developing products and environments which also respond to the inner needs of the customer.

The emotional monitoring topic – representing a major challenge, since it transcends the boundaries of the *hard sciences*, reaching the so-called *humanities* – has been deepened thanks to a collaboration with a research group of the Department of Mechanics of the Politecnico di Milano, which also includes a PhD student with a degree in Psychology. New perspective views were investigated, with (i) the integration of affective databases known in the literature, composed of images intended to arouse "basic emotions", (ii) the use of questionnaires specifically designed to assess the user's mood, and (iii) the adoption of alexithymia and empathy tests. The users, viewing these images taken from the two mostly adopted affective

databases, are acquired by a depth camera, chosen thanks to a tailored analysis of requirements and performances on three-dimensional facial acquisition [A3]. After every image view, the user answers to a questionnaire on the emotional state; using the self-assessment manikin (SAM), in order to keep track of the information on the arousal and valence degrees aroused in the subject. The subject's empathic capacity was quantified thanks to alexithymia and empathy tests, administered to the participants through questionnaires at an earlier stage. Thanks to this experimental setting, thirty-five subjects were acquired. After being analysed through neural networks, facial data were compared with those of the questionnaires; the correspondence was adequate and suggested new ideas to continue exploring the issue.

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.

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B – Design and simulation of new processes and systems

The amount of data generated continues to grow exponentially along with the digitalization of information and the use of the Internet of Things (IoT) within factories. They are increasing to such an extent that manufacturing is identified as one of the five domains in which Big Data has transformative potential. A new manufacturing model, denominated *Smart Manufacturing*, is currently attracting large interest in both academic and industrial communities, and will probably drive the manufacturing evolution in the next decade. In short, Smart Manufacturing can be defined as "*the intensified application of advanced intelligence systems to enable rapid*

manufacturing of new products, dynamic response to product demand, and real-time optimization of manufacturing production and supply-chain networks" [1].

The current project has promoted the integration among previous experiences in a unique framework, adopted to operate within the underlying assumption that the so-called Intelligent Manufacturing (IM) evolves to Smart Manufacturing along with the Artificial Intelligence (AI) evolution.

In the followings, the investigated areas involved in Smart Manufacturing for Industry 4.0 are listed, together with the main achievements reached by the team in 2020 within the project framework.

B.1 Product Lifecycle Management (PLM)

PLM provides a "Lean" approach for product development and information exchange with the production and process control areas. In this area, research has been focused on the manufacturing knowledge ontology, with the main purpose to develop a framework for PLM systems, and tackle the management aspects of product/process development. Operating both, commercial and open-source tools (NX, SAP, ARAS, ODOO, etc.), the research has also focused on the integration of PLM, ERP and MES systems [B1, B2].

B.2 Cyber Physical Systems (CPS) for Industry 4.0

Simulation tools contribute to the creation of the Cyber Physical System to develop, innovate, manage, and control the production systems by means of digital systems. The research was also addressed Digital Mock-Ups, Computer Aided Manufacturing and Tolerancing, Discrete Event Simulation, and, more generally, simulation of manufacturing and robotic processes [B3].

B.3 Lean product and process management (LEAN)

The Lean approach is an underlying concept of Industry 4.0 paradigm and comprehends effective tools (e.g., Lean 6-sigma, Value stream mapping, Lean Kata, …) that promote economic, environmental and social sustainability. An analysis of Lean approach and its impact on different manufacturing areas, as well as in different geographical regions, was also carried out [B4, B5, B6].

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B.4 Total Productive Maintenance (TPM)

TPM aims at defining the best maintenance strategy, preserving resources of the factory. Nowadays, this methodology is a general paradigm aimed at achieving maximum efficiency. It was investigated the possibility to adopt hybrid frameworks – made of physics-based models, machine learning techniques and human-centred studies – to design new AI tools for Tool Condition Monitoring and Predictive Maintenance [B7].

B.5 Human Machine Interaction (HMI)

Different versatile machines and robots, equipped with AI tools, can collaborate with humans and support them in decision-making processes. A critical point is related to the human perceptions when artificial systems operate. The development of intelligent graphic interfaces by exploiting voice assistants and/or computer vision systems could offer efficient solutions. Research activities to improve the *cobot* (i.e., collaborative robot) capabilities as effective co-workers of human beings were also carried out [B8, B9].

B.6 Industrial IoT (IIOT)

IIoTs are enabled by technologies such as cyber security, cloud computing, edge computing, machine-machine integration, collaborative robots, AI and mobile technologies. IIoTs systems are different from IoT systems, since they have less data sources, but higher rates of data frequency transmission. The relationship between IIoT systems and Cyber-Physical System has also been investigated [B10].

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C – Collaborative robots

As part of the study of Human-Robot Collaboration (HRC), the following research activities were carried-out during the year 2020:

- *Creation of a conceptual framework to evaluate HRC* [C1]. During this activity, different latent dimensions that characterize the HRC problem where highlighted (i.e., Autonomy, Information Exchange, Team Organization, Adaptivity and Training, Task, Human Factors, Ethics, and Cybersecurity). Moreover, some preliminary metrics to evaluate each dimension were provided, leading to the creation of the conceptual HRC framework. Within this framework, different collaborative applications can be evaluated and compared on the various dimensions that characterize HRC.
- *Application of the HRC framework on a real industrial scenario* [C2, C3, C4]. The previous multidimensional framework to evaluate HRC quality was tested on a real industrial HRC application in the automotive sector. Two different alternatives of the same assembly task were analyzed and compared on the quality reference framework. The comparison highlighted the framework's ability to detect the effects of different configurations on the

various HRC dimensions, including human aspects. Moreover, the framework proved to be suitable for real industrial scenarios.

- *Providing a structured methodology to support HRC configuration choice*. Identifying the configuration that better exploits the HRC potential is not trivial. For this reason, the goal of this research activity was to expand the previous methodology provided by the HRC framework to support a structured comparison of alternative HRC configurations, incorporating a Multiple-Criteria Decision Analysis (MCDA) method (i.e., ELECTRE-II) for generating a preference ranking. The description was supported by a real industrial application in the automotive field, in which four alternative HRC configurations were analyzed by a team of experts.
- *Robust programming of robots*. In collaboration with Tongji University [C5, C6], 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 the robot 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.

Enhancement of the collaborative-robotics laboratory

A collaborative dual-arm robot, mounted in a dedicated workstation, was acquired in the year 2020. The two Universal Robots UR3 arms are equipped with many tools, so that they can reproduce most industrial assembly processes. Acquired tools include:

- two-finger grippers;
- a custom-made welding gun simulator;
- a torque controlled electric screwdriver.

The expenses incurred were equal to near one-half of the budget dedicated to the purchase of robotic stations, for the project of interest.

A second robot was provided to the laboratory by COMAU in free use, i.e., a didactic e.DO robot, programmable remotely via Wi-Fi through a tablet. The robot was integrated in the laboratory in a dedicated workstation.

To maximize the exploitation of the collaborative robots, a Machine Learning (ML) workstation was acquired, provided with state-of-the-art GPU Nvidia RTX 2080 Ti, Pentium i9 CPU and 64 GB RAM. The ML workstation will run ML training using PyTorch, i.e., an open-source ML library based on the Torch library and TensorFlow.

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D – Additive production

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

In 2020, the knowledge on Directed Energy Deposition (DED) process was deepened and consolidated by a further analysis of experimental data, acquired before the COVID-19 emergency. Unfortunately, due to the unavailability of industrial partners during the pandemic emergency, the experimental activities were postponed to 2021.

An extensive review of state-of-art applications was conducted to explore the actual industrial scenario of DED adoption and future trends [D1]. In this context, Additive-Manufacturing (AM) repairing has emerged as one of the most promising applications. Optimizing the process parameters in order to increase the surface quality is at the current state one of the most challenges issues of the DED process. In addition, to improve the process obtaining a higher repeatability, it is also necessary to understand the effect of the shape and the dimensions of the substrate, that in the case of repair operations is the damaged part.

The effect of the scanning strategy on the resulting microstructure, mechanical performance and residual state of AISI 316L cubes was analysed in collaboration with material specialists

from the Politecnico di Torino's Dept. of Applied Science and Technology (DISAT) [D2]. Two main outcomes of this research are:

- Independently from the scanning strategy, the microstructural observation revealed a characteristic feature of as-built DED samples, with the epitaxial growth of columnar grains along the direction of maximum thermal gradient, that is in the middle of samples, followed by cellular structures in the last layers. By increasing the rotation angle of the deposition pattern at each new layer, the Primary Cellular Arm Spacing (PCAS) value decreased because of increment in the cooling rate.
- On the other hand, in all the deposition strategies, by increasing the height of sample, the PCAS values increased and at the last layer the PCAS value decreased suddenly due to the changes in the cooling mechanism involved in the solidification at this layer. The tensile results of 316L samples confirmed that the UTS and elongation of the samples produced by 67° rotation per layer is almost 7% and 27%, respectively, lower with respect to those produced by 90° rotation. The higher Ultimate Tensile Strength (UTS) of DED 316L samples, with respect to the conventional production processes, such as forging and casting, was found to be as a direct effect of higher cooling rates involved in the solidification of the DED samples (103–104 K/s). In fact, these high cooling rates refine the microstructure and change the phase composition of the final components that improve the mechanical strength of the alloy. The residual stress analyses of the cubes clearly indicate that on the top surfaces the residual stresses were similar for both deposition strategies, although higher stress values were observed on the lateral surfaces of the cubes produced using the 90° deposition strategy.

A second activity, conducted as well in collaboration with material specialists from DISAT, aimed to evaluate the effect of Heat Treatments (HTs) on the residual stress state and mechanical properties (stress-strain behaviour and hardness) of AISI 316L Steel processed by DED [D3]. Results of this activity confirmed the outcomes in terms of microstructural behaviour and residual stress state of as-built samples. In addition, the HTs caused the reduction and the homogenization of the hardness values which started to lose the Z dependence. The residual stresses state was strongly reduced by the HTs. The 600 °C HT allows only a partial reduction in the residual stress but keeps very high mechanical properties. The 800 °C HT, on the contrary, allows an almost complete reduction in residual stresses, but causes a 20% reduction in the Yield Stress (YS) and an 8% increase in the elongation value. The first HT might be therefore more suitable for the applications in which high strength is

required, while the 800 °C one is more suitable when complex geometries are built, and residual stress might have detrimental effects.

D.2 Automation in metal AM production

The advantages of AM are numerous, but basically the main strengths can be observed in the convenience of producing mass customized products, the complexity for free, the quick and easy management of part design changes, and the reduced use of raw materials and energy. These aspects contribute to making AM production and AM products more efficient and sustainable, since integrated and multi-functional components can be produced with reduced lead times and lightweight designs, aiming towards the reduction of energy requirements and CO2 emissions. Despite these undeniable advantages, the still limited productivity and the relatively high costs, which are typical of AM processes, have driven AM application mainly to small-medium volume production of high added-value products. Thus, the aeronautical and medical sectors are those in which AM is a key manufacturing technology, which enhances the functionality of components by simultaneously reducing weight and leading to improved efficiency, and enhances customization, by producing patient-specific prosthesis or implants.

In the automotive sector, for many years the industrial interest in AM has been limited to rapid prototyping and rapid tooling applications, to test the product design and accelerate the design phase of new products, enhance the part quality, fabricate customized tools, or reduce tooling costs. However, the potential for future development is wide, since AM is extremely flexible, agile, and sustainable.

To contribute to the digital transformation led by the adoption of AM in the automotive sector, a roadmap for the industrial application of AM has been defined in collaboration with an industrial automotive company, by addressing the challenges and valorising flexibility and added value aspects. The research was focused on the production of aluminium alloy components, where the L-PBF technology has already reached a high Technological Readiness Level (TRL).

The requirements for the development of a hybrid AM production line and its integration with conventional lines were defined, and a hybrid AM cell-based solution was proposed. As case study, some metal components were selected, and the potential benefits and open points of the proposed AM solution were identified.

D.3 Achievements

Manuela Galati, a DIGEP researcher involved in the activities of the research axis "D - Additive production", in August 2020 has obtained the prestigious "Leonardo Da Vinci" Medal (https://poliflash.polito.it/ricerca_e_innovazione/manuela_galati_vince_la_medaglia_leonardo_da_vinci). This prize, promoted by the Ministero dell'Università e della Ricerca (i.e., the Italian Ministry of University and Research), is aimed at enhancing at international level the competences and skills of the human capital of Italian Higher Education and Research.

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E – Factory logistics

The Logistics part of the project aims at creating the conditions for integration with the downstream and upstream phases of a supply chain, within the context of a 4.0 Factory [F1]. Three activities have been carried out during the third year of the project, namely:

1. Designing the layout of the plant-logistics section of the laboratory and purchasing the main components;
2. Building the digital model simulating the plant logistics operations;
3. Recruiting skilled human resources for the project implementation.

E.1 Planning and implementation of laboratory plant logistics

The plant logistics area was designed as the combination of an automated storage and retrieval system (AS/RS) and an automated material handling system that enslaves a future assembly and receiving/shipment area. The first component is constituted by a maxi-shuttle serving a single and double deep storage rack and moves both horizontally and vertically in order to access all the storage rack levels. The maxi-shuttle loads and unloads the loading units, which

are represented by plastic trays and boxes, through a vertical lift and a pulling device. The AS/RS has been developed and built by INCAS S.p.A., based on SSI Schäfer technologies.
The afore mentioned AS/RS will be coupled with two workstations integrated in the materials flow, which are constituted as follows:

- A *kitting* station served by a dedicated gravity rack. This station will simulate the preparation of assembly kits by a human operator; the kits will then be re-introduced in the AS/RS by a motorized conveyor system;
- A *picking* station to replicate the task of preparing the customers' orders for the outbound shipping.

The layout of the AS/RS, including the two workstations, is shown in Figure E.1.
The *material-handling* system is instead composed of two mobile industrial robots (MIR) able to carry up to 150 kg of material. These MIRs will be provided by TMP Engineering.

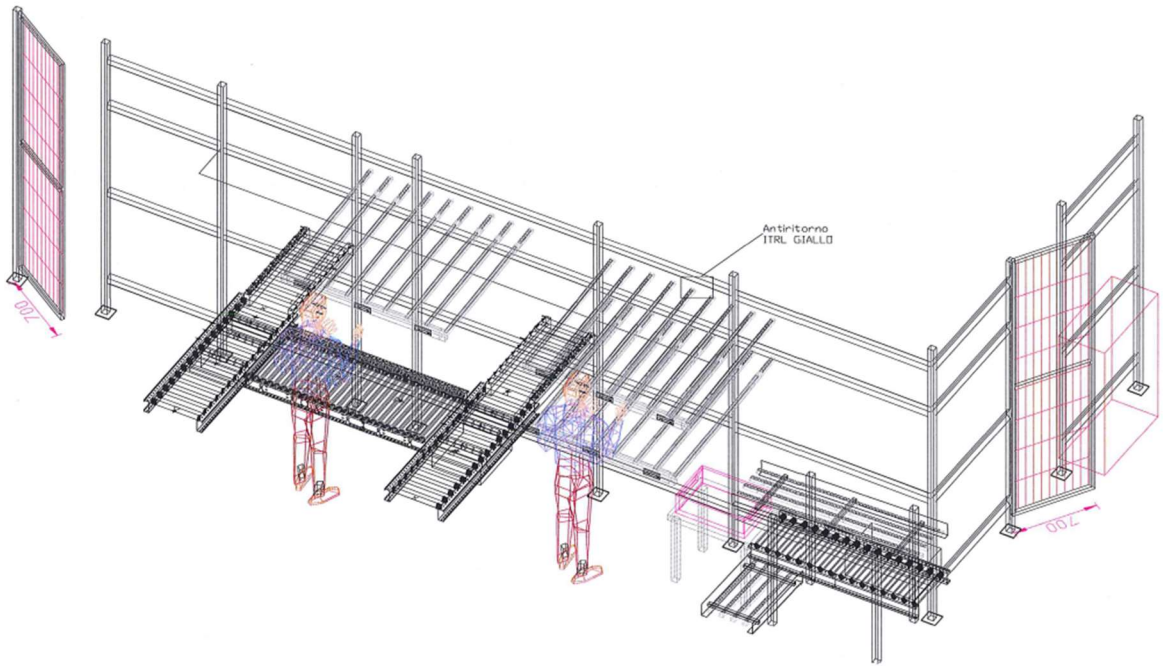

Figure E.1. AS/RS with picking and kitting workstations. Axonometric view.

E.2 Digital simulation model

A digital model to couple the existing physical flow and carry out laboratory experiments in a virtual environment was developed [F2]. The chosen simulation software is Anylogic, i.e., a multi-method simulation software that allows to define the physical boundaries and components of the area with embedded objects and classes (i.e. conveyor belt, mobile robots) as well as design the material flows via discrete-event modelling method.

Material flows and the principal operations that characterize the warehouse are represented using an UML activity diagram, which is a behavioural diagram used to describe aspects of a system, modelling the flow from one activity to another (see Figure E.2).

First simulations were performed to calibrate the parameters of the model and illustrate the results of modifying the flow of operations and changing the input parameters of the model. The input parameters are the speed of the conveyor belt and the AGVs, the order rate for materials in/out of the area, the size of the area and its main components. A scientific publication illustrating and comparing several more structured and extensive simulation experiments will be produced shortly.

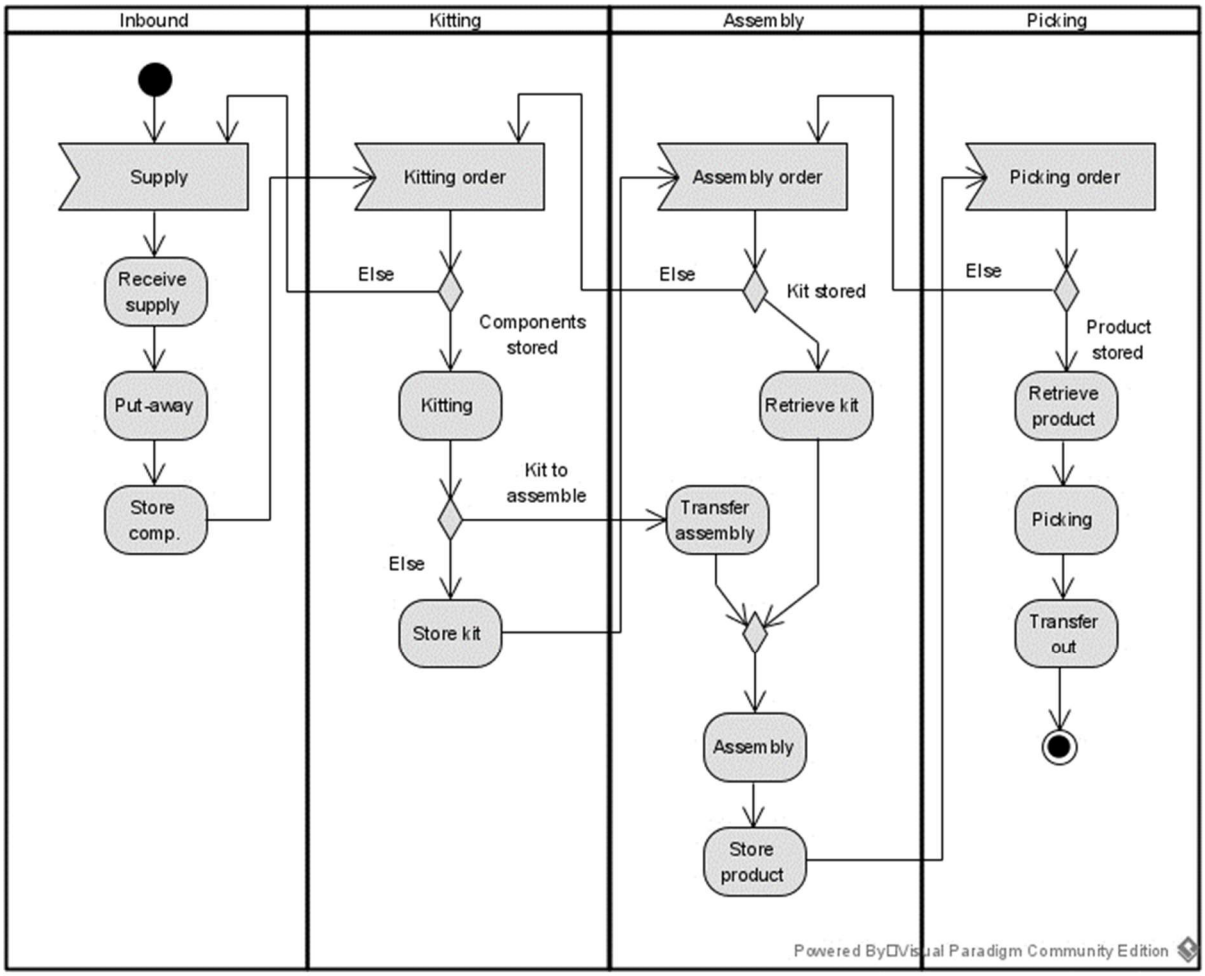

Figure E.2. UML representation of a typical logistics process.

E.3 Recruitment of human resources

The third activity is related to the enrolment of new resources in terms of two researchers (i.e., one *post doc* research fellow and one junior research fellow, during the year 2020), to develop the project and the simulation tests.

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[E2] A M.Sc. thesis by a student (Andrea Ferrari) was completed in fulfilment of this objective.

F – Quality and measurements

During the year 2020, research activity on the advanced methods for technological surface characterisation, addressed both from the metrological and application perspective, has been continued. Additionally, research on mechanical characterisation by Instrumented Indentation Testing has been carried on. The performance of existing techniques for topographical characterisation was assessed and new procedures were proposed together with methods for their uncertainty evaluation. Furthermore, the design of procedures for quality control in manufacturing processes was dealt with, by exploiting the development of models of defect generation [F1 to F5].

F.1 Deliverables

- *Metrology for Instrumented Indentation Test*: study of factors influencing measurement uncertainty of standard calibration procedures and definition of improved calibration procedures.
- *Metrology for surface topography characterisation*: definition of methods for detection and correction of disturbances in surface topography measurements based on machine learning techniques.
- *Surface topography characterisation*: development of a kriging-based methodology to augment the informativity of cheaper inspection techniques.
- Development of surface topography -based methods for tribological test characterisation and evaluation of measurement uncertainty.
- Application of instrumented indentation test and surface topography characterisation for investigating influence factors of manufacturing processes and subsequent process optimisation, in terms of surface characteristics.
- Study and implementation of *quality inspection* procedures in manufacturing processes and analysis of strategies for their improvement.
- Development of statistical models to predict defects occurring in manufacturing processes and to assess the effectiveness and total cost of inspection strategies. Several applications to

assembly manufacturing processes – i.e., low-volume and highly-customised productions – were considered.

F.2 Personnel formation and recruitment

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

- Seven undergraduate students for final projects in Automotive and Mechanical Engineering B.Sc. degrees;
- Two graduate student final projects in Mechanical Engineering M.Sc. degree.

F.3 Infrastructures

About 90% of the equipment of the laboratory of quality and technological surface characterisation has been acquired and is operational. Specifically, the following items were fundamental for the aforementioned research activities:

- 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;
- Automatic 3D scanning system with robotic cell ATOS ScanBox Series 4.

Optional moduli to extend capabilities of acquired equipment will be considered for purchase.

Another significant result for the quality and measurements laboratory is the completion of the air-conditioned *metrology cabin* within the Mind4Lab (see Figure F.1). Due to its relatively large size (i.e. more than 120 m^2), the cabin can accommodate a large amount of metrological equipment acquired or upgraded thanks to the project funds. In particular, we mention:

- Two Coordinate Measuring Machines (CMMs) – i.e. DEA IOTA0101 and DEA Global Image – which have been refurbished and retrofitted;
- The aforementioned robotic scanbox (i.e., ATOS ScanBox Series 4);
- The aforementioned state-of-the-art nano/micro-indentation systems (i.e., STeP6 by Anton Paar, AXIOTEK ISRHU09, etc.).

Figure F.1. Finalization phase of the construction of the new metrology cabin within the MInd4Lab.

By controlling the temperature and humidity conditions inside the metrology cabin, the potential of the measuring/testing instruments can be fully exploited. Additionally, the metrology cabin has a main and a secondary entrance with an automatic sliding door. The secondary entrance has been designed to allow access/exit for robotic vehicles from neighbouring laboratories (manufacturing centres, automated warehouses, robot-assisted assembly areas, etc.).

F.4 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 (ITA);
- STAM – Science and Technology in Advanced Manufacturing Team (Prof. R. Lupoi) – Trinity College, Dublin (IRL);

- TriTech – Anton Paar, Graz (AUT)
- New collaboration relationships were established with the following academic and industrial partners:
- Department of Mechanical Engineering (Prof. H.N. Hansen) – Technical University of Denmark, Kgs. Lyngby (DK);
- Department of Mechanical and Aerospace Engineering – DIMEAS (Prof. L. Mazza and Prof. A. Mura) – Politecnico di Torino (ITA);
- AGLA Power Transmission – Sant'Ambrogio di Torino (ITA);
- L.B.N. Ricerca - Sant'Ambrogio di Torino (ITA).

F.5 Achievements

Through the research activities carried out within the project, the Ph.D. candidates Giacomo Maculotti and Elisa Verna were awarded in 2020 by the SCUDO (Doctoral School of Politecnico di Torino) with the Quality Award. The latter aims to value and recognize the University's research excellence on the basis of the following criteria: scientific production, attended courses, activities of industrial relevance, awards received, and abroad mobility period. According to these criteria, Giacomo and Elisa were the only two Ph.D. candidates of the 33rd cycle of the Ph.D. Programme in Management, Production and Design to be granted with Quality Award.

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G – Sustainability

The research activities of the projects' third year were related to the sustainable development of technologies enabling the transition to the Industry 4.0. The focus was given to the economic and environmental sustainability of Additive Manufacturing (AM). Different aspects were considered when addressing the sustainability associated with the adoption of AM technologies. These were not limited to the process only, but also to the product performances and its design [G1].A framework for the economic and environmental impact comparison of (1) AM-based integrated manufacturing approaches and (2) more traditional ones – which was already introduced among the research activities of the second year of the project – was further refined and extended. Empirical-cost and energy-requirement models were suggested to assess subtractive- (e.g., machining) and additive- (e.g., Electron Beam Melting) based manufacturing approaches for the production of metal components. A life-cycle perspective was adopted, and all the steps – from the input material production to the post-AM processing operations and the use phase – were included. The analyses were carried out considering the shape of the component, the lightweighting capabilities and the utilization time as the main factors of influence. The proposed modelling effort allowed decision-support charts, which are suitable for identifying the most energy-efficient or economically advantageous manufacturing approach [G2].

The afore-described methodology was specifically applied to case studies [G3, G4]. A 'last-mile' Portable Assisted Mobile Device (PAMD) vehicle prototype was considered. The best practices of the re-design for AM were applied to three of the main structural components, and the most sustainable manufacturing approach between AM processes and the conventional ones was identified with respect to cumulative energy demand, carbon dioxide emissions and costs. The results clearly highlighted the correlation between design choices, process selection and

sustainable product development [G3]. The use of AM in the production of tooling for injection moulding was also considered. In this context, AM has led to the introduction of conformal cooling as an effective way to lower the cycle time of the process. A cradle-to-grave life-cycle assessment was used to evaluate the cumulative energy demand of conventional or conformal cooling moulds. The results showed that, although the energy demand for the creation of the conformal cooling mould could be considerably higher (due to the massive geometry of the core insert), a positive energy balance is possible after a quantifiable payback period, which essentially depends on the increase in energy efficiency of the injection moulding process [G4]. An in-depth study on performance indicators that incorporate economic and environmental sustainability was developed for Wire Arc Additive Manufacturing (WAAM), i.e., a fusion- and wire-based additive manufacturing technology, which has gained industrial interest for the production of medium-to-large components with high material deposition rates. Three components, characterized by different geometrical shapes and made of different materials, were assessed; a TOPSIS Multi-Criteria Decision Analysis was coupled with a combinatorial weighting technique, in order to generate high-resolution maps of the results [G5]. It is worth mentioning that, the latter research further extended the modelling efforts on WAAM processes, which were achieved during the second year of the project.

Regarding the AM-unit process, an experimental campaign aimed to identify the effects of the main FDM parameters on the process time and energy consumption was carried out. Components characterized by different geometrical complexities and requiring variable volumes of the support structures were printed in ABS and PC-ABS by means of a Stratasys F370 FDM machine. An inverse model correlating the Specific Printing Energy and the average Deposition Rate was proposed [G6]. In addition, the capabilities of a vibro-finishing process in the treatment of samples produced by Laser-Powder Bed Fusion (L-PBF) from AlSi10Mg powders was also analysed, with the aim of identifying alternative finishing routes for additively manufactured components made of light alloys [G7].

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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 effect of technological change on work and organizations.

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) have on competitive dynamics and on value creation. This research trajectory finds its motivation in the multifaceted and evolving role that IS can assume in organizations– i.e., the automation of existing processes (i.e., the elimination of routine work), "informate" processes (i.e., automating the way data and information are collected, processed and used to support managerial decision-making), and the transformation of the value proposition and the features of the product or the service. In 2020 the core of the activity has been on the contingencies under which IS generates business value [H1]. In H1 has been theorized and tested that the presence of structural differences between sectors leads to structural divergence in the way the business value of IS is manifested. This empirical and theoretical contribution can help scholars, practitioners and policy-makers reframe the promise of digital transformation, associated with discontinuities in such technologies as the Internet of Things, Big Data and Artificial Intelligence, into a more realistic perspective. Also, H1 illustrate that the transformation potential of such technologies might be limited to sectors that exhibit given technological, economic and managerial preconditions. Our results are robust, as far as different estimation methods and specifications are concerned, and our theoretical development indicates that these effects might persist in the future and occur in other developed countries.

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. Two studies in the hospitality industry [H2, H3] have allowed to go more in depth on understanding the impact of digitalization and the rise of new online intermediaries and platforms on the value capture dynamics of incumbent firms. By integrating a resource dependence perspective with a complementarity view, the research investigated how online visibility affects the performance of hotels, through their presence on different online intermediaries. Using 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 study found that online intermediaries increase the threats of substitute products (e.g. the supply of accommodations that are alternative to hotels) [H3], even though contingencies of different nature need to be taken into account in explaining such relationship.

Along with these studies, scholars in the Department have also conducted and finalized a stream of studies aimed at analysing the recent trends in technological developments, with special attention to the framework of I4.0. These studies are characterized by focusing on the relationships between universities and firms and of the local ecosystems. In particular, a research project funded by the European Patent Office investigated the technological specialization of European regions and of the most important universities. The project has been leading to several outputs in terms of scientific articles which support the presence of a correlation between universities that are actively exploring new fields and the specialization of local firms in novel technological areas [H5] [Hx1]. In addition, skilled human capital has been found to have a role in the processes of technological specialization: an analysis of the migration trends of inventors in Europe and the US showed such an evidence [H6]. Moreover, technological diversity as well as cultural diversity of foreign-born entrepreneurs have been found to affect regional sectoral diversification [H9]. Similarly, the characteristics of the local knowledge bases, stemming from the accumulation and recombination of competences over time, have been found to spur the emergence of new entrepreneurial activities across industries at the Italian provincial level [H10]. On the other hand, industry-diversification has been found to positively affect the creation of innovative start-ups in Italy [H11].

Finally, in this stream of studies we must also include an extensive bibliometric review of the literature dealing with the impact of Additive Manufacturing (AM) on industry, business and society has been carried out [H7]. The analysis illustrates the evolution of AM research over the last few decades, the level of concentration of the scientific community, and the geographical density of the research collaborations. In this context, particular relevance assumes the understanding of the protection of products in terms of Intellectual Property Rights. A study on digital technologies tried to improve the understanding of the effects of counterfeiting on firms [H8]. The results provide robust evidence that counterfeiting is associated to a negative impact on operative margins of affected companies and no evidence in support of the hypothesis that counterfeiting could also exert an indirect positive effect on the sales of genuine goods.

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H_2 - Technological change, managerial tensions and technology transfer challenges and ecosystems for SMEs

As in 2019, in the last year this research trajectory have been aimed at exploring the antecedents and the impact of technology adoption initiatives in SMEs and their implications for the managerial approaches. The survey on the digitalization of the Italian automotive supply chain at the international level launched in 2019 has been completed. The survey is aimed at exploring how digitalization change approaches in Human Resource Management, Industrial Relations in SMEs and value creation and capture [H14]. At the Italian level 102 firms have answered the complete questionnaire; these firms received a benchmark regarding their ability to reduce costs and change managerial processes.

Similarly, a research line investigating the trajectories and patterns of adoption of Industry 4.0 technologies has been continued. First, this line of research focuses on the study of the strategic levers that lead SMEs toward the decision of adopting Industry 4.0 technologies and -secondly- on the role that other players within the business ecosystem (e.g. universities, research centres, system integrators) play in encouraging both the adoption of technologies and the recognition by SMEs of the opportunities linked to 4.0 technologies. In order to carry out this study, a collaboration was set up with the Turin Chamber of Commerce, which led to the collection of data and the creation of a database of companies belonging to the Piedmont region. This streamline of research has led to H12, in which the issue related with the strategic adoption of Industry 4.0 technologies has been explored both from a theoretical and from an empirical standpoint. The key results show that broad collaboration strategies (weak collaborations with many actors of the ecosystem) promote the recognition of strategies related with operational efficiency, while deep collaboration strategies (intense collaborations with few actors of the ecosystem) promote strategies related with the development of new products. This research contributes to the emerging literature on the adoption of 4.0 technologies and provides prescriptive indications to managers on how which collaborations they should set up and cultivate, conditioned on the use they aim to have of 4.0 technologies.

Starting from these premises, a natural evolution of the research concerning the adoption of Industry 4.0 technologies is related with their effect on the performance of SMEs. In this vein, a new line of research has been open with the aim of exploring the complementarities between different Industry 4.0 technologies, between their potential application (e.g. smart manufacturing, smart working, design of smart products), as well as the relative impact on the performance of SMEs (both from an operational standpoint -e.g. with reference to the

efficiency of the production systems- and from an economic standpoint -e.g. in terms of economic performance). This research line is currently in a development phase. During 2020 the objectives of the research have been set. Moreover, it has been conduced a review of the current literature on Industry 4.0 aimed to identify a comprehensive picture of both the technologies associated with the 4.0 phenomenon and the applications of 4.0 technologies. Finally, a preliminary series of case studies (3) have been conducted to test the interview protocol aimed at letting emerge the complementarities between technologies and applications. The study is expected to be concluded by 2021 and the first paper to be sent to a scientific journal by early 2022.

As far as technology transfer is concerned, the emergence of the COVID-19 has stimulated the analysis of small firms, as academic spinoffs, to investigate how the pandemic has changed the development of their products, as well as how remote working and barriers related with the lockdown have been breached by such firms to continue their activities in these difficult times. More specifically, although digitalization can favour remote working and the contact with customers, the limitations imposed by the pandemic have reduced the opportunities for spinoffs -and more in general for small firms- of developing new products and testing them with customers. Potentially, this slowdown could have serious impacts on the survival of such firms as -given their limited availability of funds- they usually need to reach the market as fast as possible. Therefore, in H13, we have explored how an Italian spinoff have drawn within a set of capabilities accumulated within the previous years of activities to quickly reconfigure its business model by developing a new product to contribute to the fight against COVID-19. Among the most interesting results brought by the research, one is specifically relevant for the project as it has shown that the capability to work remotely through the assistant of specific software, developed by the founding team within previous years, has been crucial in favouring the development of a product completely new to the firm within only 15 days.

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H_3 - 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 cultural heritage, who represent two extreme cases where the phenomenon of technological change is more evident than in other contexts. The research being conducted in the electrical sector capitalizes the mid-term relationships established with the main electrical employer associations in Italy (Elettricità Futura and Utilitalia) and with Enel, one of the largest power generation and utility company in the world. Specifically, the research conducted in 2020 has analysed through case studies how Covid-19 has accelerated and changed the use of smart work practices. The study highlights the organizational implications of the evolution of smart work from a measure of life-work balance for few employees into the "new normal" way of working for white collars employee, i.e., the need of new leadership approaches for middle managers, the evolution of control systems, the need for increased autonomy and organizational citizenship in employees.
The research lines on the electrical sector and the automotive sector thave allowed to build a training development project with EIT Manufacturing, the 7 year research program funded by European Commission and aimed at promoting technology development, education and technology transfer on the fields of digital manufacturing. Specifically, the project has been funded for 123 k€ by EIT Manufacturing, it has been conducted during 2020 with the aim of developing training content for open online courses on the work transformation ignited by digital technologies. The course targes managers and production specialists in the settings of SMEs as well as students in specializing masters and master of science programmes in - industrial and management engineering.

A second research setting on which the Department has decided to conduct its research on the relationships between digital technologies and digital transformation is cultural heritage [H15, H16, H17, H18]. A first study conducted in 2020 shows that institutional differences in an industry matter and should be included in theoretical and managerial contributions to vertical

disintegration brought about by technological change [H15]. Through multiple case studies on the cultural heritage industry, conducted in different countries, the results show that gains from specialization and transaction costs depend on the institutional environment. Institutional settings where museums had flexibility in competency acquisition led to higher coordination costs than museums with a new digital distributor entering the sector: Google. In these contexts, museums opted for vertical integration, even if new specialization patterns emerged due to technological change. On the other hand, in environments that hindered the diffusion of the new norms and values needed to cope with the new specialization, museums responded less effectively to the technological change, opting for a less vertical integration. Furthermore, since new cultural needs arose from the COVID-19 pandemic that hit and forced the world to a state of cultural fasting, a second study [H16] aims to study the role that digital innovation can play within the overhaul of the information chain of the cultural and creative sectors and the value creation opportunities that actors and stakeholders can exploit. Specifically, H16 shows that technology augments, complements and amplifies the way people experience their cultural interests and experience. Digitization allows visitors of virtual museums to focus on artworks and to detect very small details that commonly could not be seen during an on-site visit. Furthermore, the study shows a process of democratization of art since museums can exploit new digital and virtual ways to distribute art globally. Lastly, to nail down the mechanisms of the relationships between digital technologies and digital transformation in the cultural heritage setting, a specific and unique database on 4.500 Italian cultural institutions was developed in order to: (a) identify the organisational roles and professional skills involved in the digitisation process; (b) identify the activities that represent a factor of change in the digitisation process; (c) analyse the impact of organisational changes as a function of institutional policies and digital strategies. In this vein, drawing on the above-mentioned database on 4.500 Italian cultural institutions, H17 empirically shows how the legacy activities traditionally conducted in the cultural sector influence museums' performance (i.e., revenue and visitors) and how the digital transformation moderates such process. In the same way, H18 empirically shows how the organisational roles within a museum (i.e., governance, curation, conservation, education, digitisation, communication) influence its performance in terms of revenue and visitors, and how the level of vertical integration moderates such process.

Finally, the Department has won a research project on digitization and active labor policies, aimed at giving indications for the organizational transformation and governance of employment centers (DIGIPAL). The project has been funded by the National School of Administration (SNA), Presidency of the Council of Ministers, through a competitive tender,

indexed as "For a new Public Administration" Area II - Realizing the digital transformation. The objective of the project is to provide new evidence about the impact of digitization on public institutions involved in the design and implementation of active labor policies, to formulate policy indications. Content: analysis of the effects of the digitization process on the administration of active labor policies about i) the nature of the goods and services provided; ii) the technological and organizational transformations necessary to adapt public administrations to technological and market changes; iii) the professional profiles (both managerial and technical) and the skills instrumental to this transformation; iv) the opportunities and risks associated with the use of data-driven technologies in the decision-making and implementation processes of active employment policies. To conduct this project, the Department has created a research team that is multidisciplinary, composed of experts in public policy analysis (social and labor) and governance studies, management engineering and technological innovation and organizational studies, innovation and labor economics. The Methodology of the research is qualitative, with desk phases and field surveys, through the carrying out of comparative case studies in Italy and in selected European countries (Austria, Finland, Belgium / Flanders, Netherlands, Germany). Case studies will be based on conducting in-depth interviews with experts with at least 20 years of work seniority in Public Administration.

The other significant research program launched in 2020 has involved INAPP, the Public Policy Italian Institute, a public research body supervised by the Ministry of Labour and Public Policy. INAPP collaborates with European institutions and is part of the National Statistical System (SISTAN). It plays the role of methodological and scientific assistance for the system actions of the European Social Fund and is the National Agency of the Erasmus + Community program (link is external) for the education and vocational training sector. INAPP's goal is to contribute to the scientific, economic and social development of Italy. The Institute's research activity is aimed at studying phenomena of strategic importance for the community, to provide information, knowledge and useful tools for the policymaker to make their own choices and for citizens to assess the impact of these choices. All this also means building public goods such as databases for the world of research and for those called to make decisions in favor of the community.

The goal of this research is to conduct exploratory case studies and focus groups with experts to understand wow digital technologies is changing work and Human resource management practices, skills, organization structures in a variety of sectors. Specifically, case studies explore all the manufacturing industry (using Woodward taxonomy) at the country level, whereas focus groups involve experts from education institutions and HR managers from companies that are leaders in their supply chains and can act as active actors in the transfer of new work practices towards companies.

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H_4 - 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) (H19, H20). In order to test these research questions, a Randomized Control Trial (RCT) was organised. The RCT involves about 500 early-stage start-ups from Italy. The start-ups have been then randomly allocated to two different treatments: the teaching of the scientific method (treatment 1) or the effectual method (treatment 2), or to a control group which has been treated with a heuristic method (placebo). Groups are then taught with the methods for about six months, and their performance (e.g. quit, pivot, revenue) will be monitored over the next year and a half to assess the effectiveness of the scientific method versus the effectual method or the heuristic method.

Furthermore, in 2020 the first RCT on the decision-making processes of early-stage entrepreneurs has been concluded its data collection phase and has led the researchers to investigate whether the application of a scientific method for decision-making to entrepreneurs with a background in scientific fields as science, technology, engineering or mathematics can be marginally beneficial compared to those entrepreneurs without such background [Ne]. This research line has shown that although the scientific method seems to be beneficial concerning the decision to quit their idea soon and to limiting the number of pivots made by entrepreneurs, it seems to be detrimental to the performance in terms of revenues. In other words, more scientific entrepreneurs tend to overthink on their idea and this can be beneficial to save time and money by pivoting or terminating earlier, but detrimental for the execution.

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I - Algorithms and their influence on decision making processes

The 2020 activity continued focusing mainly on production scheduling and packing problems but considering also bi-level and graph problems on a side and combinatorial design on another side.

In terms of production scheduling, the so-called two-machine flow shop problem with three operations and as objective function the minimization of the makespan was tackled. Peculiarity of this problem is the presence of one operation that can be either processed on the first machine or on the second machine. By exploiting the modeling of this problem as a special case of another two-machine flow shop problem with common due date and jobs selection, an exact constraint generation approach is devised capable of solving in limited time very large size instances [I1]. In [I2], the matheuristic approach proposed in the previous year for selective disassembling sequencing under sequence-dependent costs was finalized and eventually published.

Exploiting the presence of Prof. V. T'kindt as visiting professor, the application of exact exponential-time algorithms and approximation algorithm for parallel machine scheduling problems was tackled in [I3]. Also, a unifying framework for implementing memorization into search trees for sequencing problems was successfully applied to several well known paradigmatic problems in [I4]. The research activity on bilevel scheduling in single machine continued in 2020 and polynomially solvable cases were proposed in [I5]. Dynamic programming solution approaches for lot streaming in flow shop scheduling were proposed in [I6].

In terms of packing problems and in the quest of bi-level optimization, the work on the Bi-level Knapsack problem with Interdiction Constraints was finalized and eventually published in one of the leading international journals in Operations Research [I7].

The activity dedicated to the application of operations research and artificial intelligence techniques to combinatorial design problems was continued in 2020. The work proposed on the Oberwolfach problem [I8] was eventually published and new research activities combining combinatorial optimization and combinatorial design applied to nurse rostering induced by a practical problem proposed by a private hospital in Turin started. Preliminary investigation indicates that balanced cyclic nurse rostering patterns inducing the same schedule for all nurses (so that the weekly schedule for n nurses corresponds to the schedule for each single nurse of n consecutive weeks) can be generated by ILP modeling complying with all main rostering

requirements for limited size in n. Interestingly enough, such patterns appear generalizable to large sizes of n. This research stream is currently on-going.

Another line of activity of major impact was dedicated to operating rooms scheduling of elective surgeries. This activity, in close cooperation with "ASL Città di Torino", received a strong boost from the COVID pandemic as elective interventions faced a significant reduction in operating rooms availability. Correspondingly, "ASL Città di Torino" asked for support in deriving a monthly schedule providing a fair assignment of the operating rooms to specialties. The related problem was tackled by means of optimization models taking into account surgery waiting lists, post-operation beds availabilities and various other operational constraints. As an outcome, a software prototype has been developed and is currently under operational testing.

Further activities on graph problems were also provided in [I9] where the work on the so-called maximum happy vertices problem, that involves determining a vertex coloring of a graph such that the number of vertices assigned to the same color as all of their neighbors is maximized, has been finalized and in [I10] where the final version of a paper on the Stochastic Critical Node Problem (CNP) with the goal of minimizing the pairwise connectivity of a graph by attacking a subset of its nodes has been published. Further activities on decision making were also proposed in [I11, I12].

The following other works [I13, I14, I15] not mentioned above were also published in 2020.

In terms of dissemination, the organization of the next MAPSP (Models and Algorithms for Planning and Scheduling Problems) Conference that was attributed to our Department with F. Della Croce as Chair of the Organizing Committee was confirmed but postponed to June 2022 due to the COVID pandemy. The Conference is expected to take place at Oropa Sanctuary (BI), Italy.

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L - Algorithms for complex production systems and supply chains

The research activity of the group focused (1) on the investigation of algorithms to efficiently and effectively solve large simulation-optimization MILP models and other complex production planning problems, and (2) deepen the study of eco-industrial parks.

Research activity (1) aimed at exploiting well-known techniques as Bender's decomposition and Lagrangian relaxation to deal with problems for which such techniques were never used previously in the literature. Specifically, Lagrangian relaxation was applied to the solution of discrete lot streaming problems, coupled with dynamic programming [L1]. Bender's decomposition, instead, was adopted to devise a new solution framework for simulation-optimization problems in which simulation is explicitly considered (white box simulation) and feasibility cuts are found from simulation to find the optimal solution. Such approach has been applied to the buffer allocation problem [L2] and to the more general resource allocation problem [L3].

In the research on production systems, also techniques to automatically update digital twins have been studied. The aim is to guarantee a continuous alignment between production system models and real systems. The final objective is to create and keep updated the digital twins by

using data gathered through sensors placed on the real system. At the current stage of the research, only the initial phase, i.e., the change detection, has been investigated [L4].

In the research line focused on algorithms applied to complex systems, supply chains have been also considered, by addressing the bullwhip effect phenomenon. [L5] investigates the impact of the unknown demand process parameters on the increase of demand variability through the echelons of the supply chains (i.e., on the bullwhip effect); the study highlights that the bullwhip effect is not only affected by the unknown demand parameters, but also by the frequency with which the parameter estimates are updated.

About the research on eco-industrial parks (2), the objective has been to develop a methodology to improve economic and environmental performance of the production system through both the reduction of produced waste and the exploitation of the remaining ones within relationships of Industrial Symbiosis. The proposed methodology has been applied to a case study [L7]. Furthermore, the link between the network level (Eco-Industrial Park) and the operational level of the firms has been preliminary investigated with the twofold goal of: (i) foreseeing the maximum potential benefits achievable by each individual firm; (ii) decoupling the part of the production system devoted to the various Industrial Symbioses from the one for the core business [L6].

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1.3 Economic and Legal Perspective

M - Economic perspective

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

2) 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], 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.

Other studies, already started in the second year of the project, have been mainly directed on studying the interplay between regulation, ultra-fast broadband connections and their impact on the economic system. From a regulatory perspective, contributions [M2 and M3] focus on role of co-investment and new access policies to foster fiber based network deployment. These studies, finalized and published, helps National Regulators to find possible solutions on the implementation of the recent European Electronic Communication Code (Directive n. 2018/1972). Contributions M4 and M5 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. 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 contract** for the year 2020 with TIMLab. On this topic, the research group has also started **a new 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.
Finally, a new project [M6] has been started thanks to a **new 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.

On the issue of microeconomic effects of new technologies on firms, a research in collaboration with **Università di Milano** *(Department of Economics, Management and Quantitative Methods)* investigates 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), by exploiting a uniquely rich longitudinal matched patent-firm data set on firms filing 4IR-related patents at the European Patent Office (EPO) [M7]. The paper finds a positive association between the stock of 4IR patents and firm-level performance, but not profitability. The effect is stronger in companies investing in 4IR technologies more recently (i.e., after the mid-2000s), in companies that have shown less continuity in patenting, and in firms whose patents combine different technological domains associated with 4IR and have a stronger content of downstream applicability, hence closer to the market. The research team has also developed a novel and in-depth analysis of the technological trends, geographic distribution, and business-level dynamics of 4IR in the European Union from patent- and firm-level perspectives, by analyzing

the patents filed at the EPO between 1985 and 2014 [M8]. The paper finds evidence of a surge in the patenting activity related to 4IR in the past three decades, particularly in networked devices. Results suggest that firms filing 4IR patents have become progressively younger on average. At the same time, the paper documents a steady growth in the average number of 4IR patent applications filed yearly by each company. Variance decompositions show that the surge in 4IR patent applications is mainly explained by incumbent firms filing more 4IR patent applications over time, rather than new entrants progressively populating the 4IR world. The paper also uncovers a general trend emerging at the firm level, whereby firms tend to specialize in a few technological areas and avoid differentiation.

On the issue of the impact of new technologies on firms' behavior, some members of the department have been awarded a VisitINPS scholarship to be started in February 2021. The scholarship allows the researchers to use individual-level data about the population of workers in Italy. The main aim of the project (developed in collaboration with some researchers of the Henley Business School, University of Reading, UK) aims at investigating the effect of backshoring (i.e. the relocation at home of production facilities previously delocated abroad). A side aim is to investigate the role in this process of Industry 4.0 technologies and to assess whether the use of those technologies facilitates or not backshoring.

3) As for the implications of new digital technologies on consumers' privacy, the research focuses 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 [M9 and M10]. 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 [M10] 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. The design of the consent policy and its effect have been also considered. On the empirical side, two brand new studies focus

on the impact of privacy regulation. In [M11] 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. The goal is to compare EU vs US web traffic before and after GDPR introduction. Preliminary 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 [M12] 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 **new collaboration** with a researcher of *DG Competition – European Commission* (Bruxelles).

4).As for AM adoption, two additional surveys have been run, one in the dental office and the other in the goldsmith industry. The first one, run on a sample of dentists in the Palermo area, has allowed to qualify previous findings obtained with another survey covering the Torino area [M13]. In particular, dentists are aware of the technology and its advantages but they prefer not to invest in the technical skills necessary to properly use such a technology. As for the goldsmith industry, a survey has been run in the Vicenza industrial district. The survey has highlighted the wide use of additive manufacturing in 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 [M14].

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N - Legal perspective

Following the main guidelines of this project related to the data-driven society and the new era of machines, legal research in the second year focused mainly on AI, including data security, 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,[2] 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 in the third year of this project focused on four main areas: (1) AI regulation, (2) data security and cybersecurity, (3) 3D Printing and product liability, and (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 ongoing work of the Ad hoc Committee on Artificial Intelligence on the Feasibility study on a legal framework on AI design, development, and application (2019-2021) [N2].

In 2020, the current European debate on Artificial Intelligence and its polarisation between the initial ethics-based approach and the growing focus on human rights was investigated.

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

Assuming the need to consider the role of ethics as a complementary element of a regulatory strategy that must have human rights principles at its core, the research focuses on the role that the international human rights framework can play in defining common binding principles for AI regulation. In this regard, as a wide range of AI-based services and products have only emerged as a recent development in the digital economy, most existing international legal instruments are not tailored to the specific issues raised by AI. Against this background, we examined the existing international human rights instruments and extracted key principles that should underpin the development of AI and govern its ground-breaking applications. As the paradigm shift brought about by the latest wave of AI development means that the principles embodied in international legally binding instruments cannot be applied in their current form, an addition layer of this research concerned the contextualisation of these guiding principles for the AI era. Given the broad application of AI solutions in a variety of fields and the methodological approach adopted, this analysis focuses on two key areas (data protection and healthcare) providing a first assessment of the regulatory issues and a possible roadmap to addressing them [N1].

Furthermore, this research has benefitted from the synergy with the concurrent research project conducted by the Ada Lovelace Institute (UK) "Rethinking Data" (2020-2021), in which prof. Mantelero is involved to investigate the collective dimension of data protection issues in the AI context.

Conference presentations:

- [Belgium] CPDP2020 Computers, Privacy and Data Protection conference, Brussels, 23 January 2020, conference panel organised by the Council of Europe, AI and Human rights: what is the Council of Europe doing for you? (Mantelero, invited speaker)
- [Switzerland] EPFL, Applied Machine Learning Days, Lausanne, 27-29 January 2020, AI and Humanitarian Action (Mantelero, invited speaker)
- [Belgium] European Data Protection Supervisor, Workshop: Artificial Intelligence and Facial Recognition: the EU Approach, Brussels, 13 February 2020 (Mantelero, invited speaker)
- [Greece] European Public Law Organization (EPLO), Quo Vadis AI Conference, Athens, 21 February 2020 (Mantelero, invited speaker)
- [Germany] Academy of European Law, Annual Conference on EU Data Protection Law 2020, Trier (online), 25 June 2020 (Mantelero, invited speaker)

- [Spain] III Digital Law World Cogress (2020): “Digital rights: a new evolution of Human Rights”, Barcelona (online), 23 October 2020 (Mantelero, invited speaker)

References

[N1] Mantelero, A. 2020. Regulating AI within the Human Rights Framework: A Roadmapping Methodology. In Czech P., Heschl L., Lukas K., Nowak M., Oberleitner G. (eds) European Yearbook on Human Rights 2020. Intersentia (Cambridge). ISBN:9781780689722, 477-502

[N2] Mantelero, A. 2020. Analysis of international legally binding instruments. In Council of Europe, Towards Regulation of AI Systems. Council of Europe Study (Council of Europe, 2020)

N_2 - Data security and cybersecurity

This is the most interdisciplinary field among those investigated in 2020, also due to the synergy with the H2020 research project "CyberSec4Europe" (Cyber Security Network of Competence Centres for Europe), where prof. Mantelero is task leader (Legal and regulatory requirements). Our research focused on the interplay between data protection and cybersecurity regulations. In this regard, there are several sector-specific studies on EU data protection and cybersecurity frameworks in the literature, but their differing legal domains have hindered the development of a common analysis of the different sets of provisions from a business perspective.

The research we conducted in 2020 in this field [N3] sets out to bridge this gap by providing a systematic review and a cross-cutting operational analysis of all the various provisions that constitute the common European approach to personal data and cybersecurity regulation. We have demonstrated the existence of a core of common principles and procedural approaches referring to specific cybersecurity and data security technologies. This analysis revealed a coordinated regulatory model based on five pillars: risk-based approach, by-design approach, reporting obligations, resilience, and certification schemes. We also highlighted the relationship between the directives and the regulations.

Conference presentations:

- [Belgium] CPDP2021 Computers, Privacy and Data Protection conference, Brussels, 28 January 2021, conference panel on “Cybersecurity for Europe: Fostering Rights Through Technology” (Moderator: Athena Bourka, ENISA; Speakers: Alessandro

Mantelero, Polytechnic University of Turin; Giuseppe Vaciago, University of Insubria; Vanesa Gil Laredo, BBVA; Marko Hölbl, University of Maribor)

References

[N3] Mantelero, A., Vaciago, G., Esposito, M.S., Monte, N. 2021 (in press). The common EU approach to personal data and cybersecurity regulation. International Journal of Law and Information Technology

N_3 – Product liability and 3D printing

This ongoing research activity focuses 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 us to rethink traditional liability dynamics for an optimal allocation of damage costs. In the light of the recent reform proposals made by the EU Commission, it is important to consider whether and to what extent liability can encompass new emerging players in 3D printing production and add specific safety and quality obligations. Moreover, to ensure an adequate level of protection, it is necessary to redefine the notion of 'product' considering its digital dimension.

This research also benefits from the synergy with the research group on additive manufacturing, coordinated by Prof. Iuliano, which also includes the supervision of a PhD thesis on 'Additive manufacturing and regulatory issues'.

References

[N4] Esposito, M. S. La responsabilità per danno da prodotto difettoso nel contesto della stampa 3D e il ruolo delle piattaforme online (forthcoming).

N4 – 3D printing and IP protection and impact of AI on corporate governance

As for Additive Manufacturing, on 3 July 2018 the European Parliament adopted a Resolution recognizing the importance of Intellectual Property in the area of Additive Manufacturing. IP rights are one of the most controversial issues in the discussion about AM and the need to adapt the IP regime is often questioned. Nonetheless, there is still a lack of consistency in the application of the law relating to 3D printing and, in particular, of the copyright law relating to the file CAD, the design contained within the file and the physical object to be printed. This lack of clarity can represent an obstacle for the further diffusion of the technology. It is therefore essential to understand what the CAD file is from a legal perspective and, even before <that, what AM consists of, how this technology came about and how it developed over time, from a technical point of view. For this purpose, the research is exploring the copyright status of the CAD file, benefitting from a multidisciplinary approach, which – as recommended in the 20202 report of the Advisory Board – has been allowed by the synergy with the ongoing VAMP project (Valutazione multidisciplinare delle performance tecnologiche e di sostenibilità di differenti sistemi di fabbricazione Additiva per la realizzazione di componenti in materiali Metallici e Polimerici) directed by Prof. Paolo Priarone.

A separate research stream that the business law group will follow relates to the interaction between AI and corporate governance of large and medium size corporations: one of the true advantage of AI in corporate governance is the ability to gather, process and analyse data to support management decisions by executives and better assess strategic options by the board of directors. Data-driven decisions supplemented with AI may improve capital allocation, disbursement of funds, investment guidance and risk management and, more in general, contribute to increase the accountability of management decisions. On the other hand, there is a significant area of risk to explore from a legal perspective, namely the scope and preconditions to reliance on AI-generated suggestions/analysis and liability profiles in case of failure or mismanagement.

References

N5 Rivaro, R. Analysis of the impact of 3D-printing on IP rights (forthcoming)

2 Update on project budget at December 2020

The Table below sketches in a nutshell the actual expenses and related 2018-2020 budget compared to the planned ones.

PLANNED VS ACTUAL BUDGET 2018-2020

Relevant entry	**Planned 2018-2022 costs/grants/positions**	**Actual 2018-2020 costs/grants/positions**
Equipment and infrastructures	**2875 k€**	**€ 1,931,266.41** (of which **€ 559,242.00 payments 2020** and **€ 609,800.00 commitments 2020**).
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) **1 RTD-A position filled** (Grinza) **6 RTD-A positions announced** (to be filled by mid 2021)
Post-doc fellowships	**12 fellowships**	**9 fellowships** (Altavilla, Barravecchia, Battaglia, Nebbia, Pastore, Pesce, Piscopo, Sabatino, 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**	**2.5 Visiting Professor position** (T'kindt renewed for years 2020-2022)

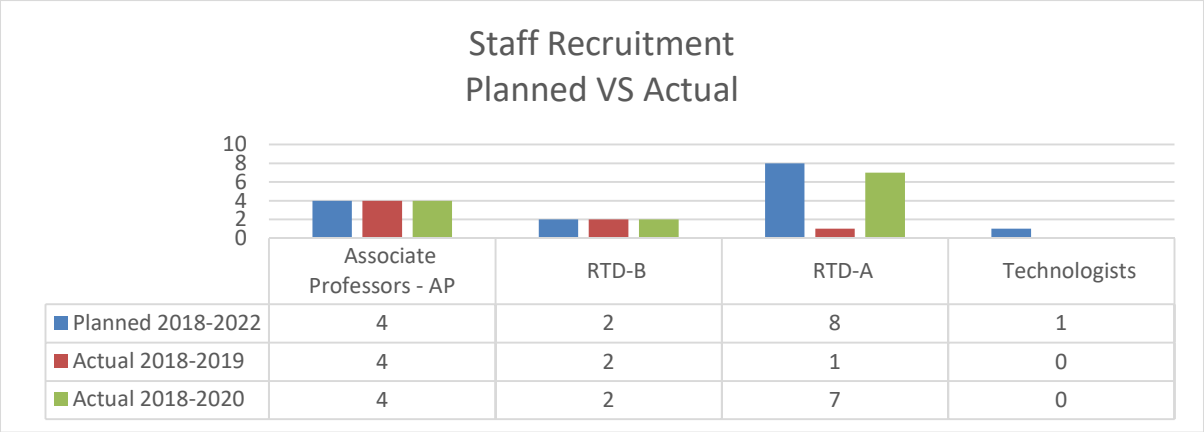
As we can see, approximately 67% of the planned budget for the total expenses in equipment and infrastructures referring to the entire project has been spent in 2018-2020. In detail, € 1,169,041.61 is the actual budget referring to the year 2020, of which € 609,800.00 refers to the committed budget for the purchase of new equipment, that will be reported in 2021, for which we have already started the purchase procedures.

The foreseen associate professor positions and RTD-B positions have all been filled; 1 RTD-A position was filled last year and 6 other positions are planned to be filled by mid-2021. Regarding the two-years post-doc fellowships, 9 postdoc fellowships have been assigned out

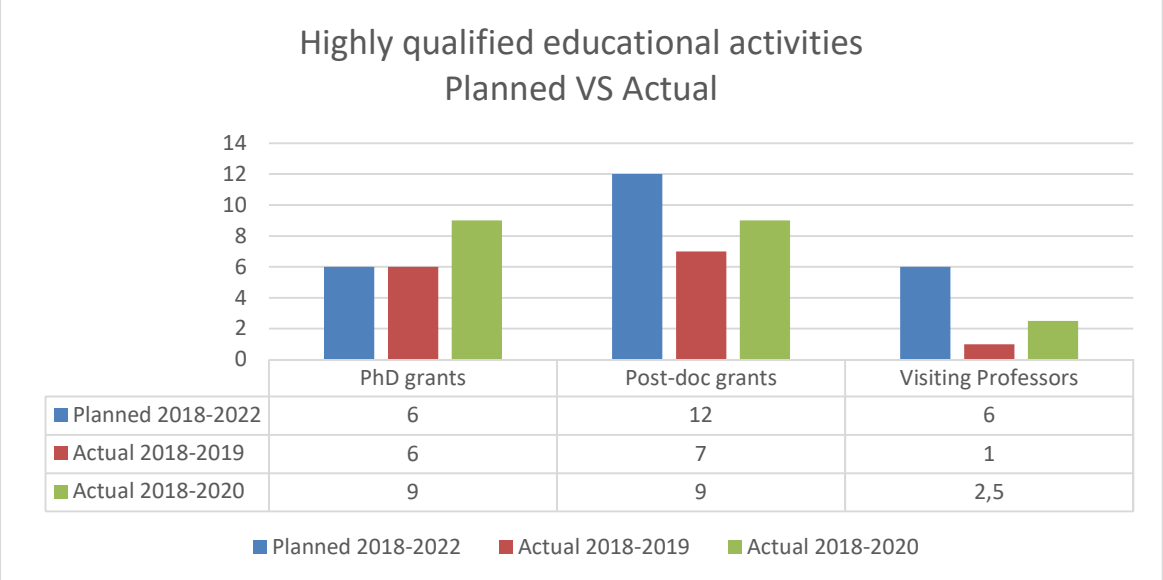
of a planned total of 12. For five of these, a one-year extension was activated at the end of their two-year fellowship, thereby using some of the remaining budget available for 2020-2022. As for the PhD fellowships, in total, in the period 2018-2020, 9 fellowships have been assigned (1 fellowship has been activated in 2020), 2 of which are co-financed by the DIGEP. Finally, 2.5 visiting professors' positions have been activated so far out of a total of 6 positions planned in the project.

Overall, the actual budget is reasonably in line with the planned one.

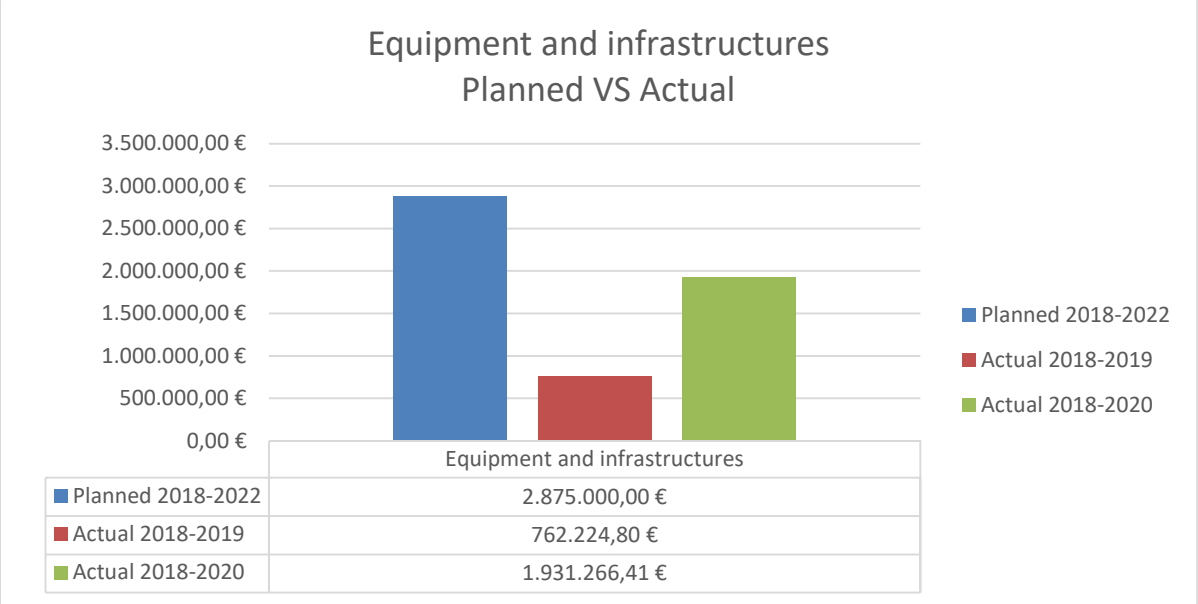
Below are proposed some charts detailing and comparing the current situation (2018-2020 period) with the first two years of the project (2018-2019 period) and the planned situation for the entire project (2018-2022 period).



	Associate Professors - AP	RTD-B	RTD-A	Technologists
Planned 2018-2022	4	2	8	1
Actual 2018-2019	4	2	1	0
Actual 2018-2020	4	2	7	0



	PhD grants	Post-doc grants	Visiting Professors
Planned 2018-2022	6	12	6
Actual 2018-2019	6	7	1
Actual 2018-2020	9	9	2,5



	Equipment and infrastructures
Planned 2018-2022	2.875.000,00 €
Actual 2018-2019	762.224,80 €
Actual 2018-2020	1.931.266,41 €

3 Activity for the incoming year 2021

The research activities for the incoming year will be devoted to deepen and prosecute the ones of year 2020 with the objective of catching up some of the delays induced by the COVID-19 pandemic. Below are indicated the foreseen activities with respect to the specific research axes.

A - 3D modelling and simulation

The research objectives for the year 2021 are:

- the creation and validation of *ad hoc* virtual reality environments, aimed to arouse specific emotions;
- to complete and validate the acquisition set-up and the analysis of obtained facial data;
- to build a public database of emotional faces based on 3D data.

Long-term objectives also include the design of a tailored neural network, which could be able to categorize not only the six basic emotions but also the expanded set of emotions, which are more common in the product development context.

B - Design and simulation of new processes and systems

In the year 2020, it was also finalized the design of "Fabbrica Collaborativa Lab" (Collaborative FabLab) and enlarged the testing activities on the IoT Mockup Light Lab. The IoT Mockup Light Lab devices have been funded with private resources because of the required flexibility in the acquisition of experimental components. Consequently, the costs currently charged on the project budget are quite limited (about 10% of the overall budget), as the largest amount of expenses has been allocated for the implementation of the Collaborative FabLab, which will be finalized within the first half of 2021.

C - Collaborative robots

To complete the development of the collaborative-robotics laboratory, it is still necessary to acquire a robotic cell, in which the robot works according to the concept of Speed and Separation Monitoring (SSM). According to this procedure, the robot will be equipped with a couple of scan lasers to monitor the presence and the movements of the human workers and

allow to maintain a safe distance from the robot, proportionally to the relative human-robot velocity. This kind of experimental setup is not commercially available and will be custom designed for the objectives of the laboratory.
Further additions will be a Lidar, i.e., a laser device for measuring distances that can be used to make digital 3D representations of the environment. The Lidar will be mounted on the robot arm or on an external tripod, depending on the applications.
The UR3 robots were provided with a dedicated training course that was not taken due to COVID and will be postponed. As a matter of fact, robot training must be executed in presence and not by remote teaching.

D - Additive production

Based on the requirements and specifications for the DED system, defined in 2019, a LASERDYNE® 430 has been purchased and will be installed in the first quarter of 2021. This open Additive Manufacturing platform allows the access to the main parameters of the system and can be used for (i) material and process characterization/optimization, (ii) addition of internal and external features, (iii) coating deposition and repair or (iv) build up activities on existing parts. The DED system has been partially founded by Politecnico di Torino and this system will be used in 2021 to carry out the experimental activities foreseen within the project. With the acquisition of the DED system, in 2021 the 90% of the budget for equipment will be spent. A 60% of the research activities were concluded at the end of the 2020.
The research activities in 2021 will benefit from the availability of the DED system and will be focused on the optimization of process parameters. Moreover, the experimental activity will be supported by numerical simulation modelling, using ABAQUS and Netfabb software tools [D4], in order to predict and identify the most suitable process parameters window, from meso-level (deposition tracks) to macro-level (deposition volume).

E - Factory logistics

In 2021, the attention will be focused on installing the AS/RS and the two MIRs, together with a Warehouse Management System (WMS), i.e., a software able to plan and schedule all the activities taking place in the plant logistics area, and a middleware software connecting all physical and informational flows. The laboratory will also be enhanced via the purchasing of other such as the RFID gate and a cloud server for data repository and communication. Then,

workbenches will be installed close to the storage system in order to propose two typical activities carried out in warehouses, namely light assembly of components and order kitting of finished products.

F - Quality and measurements

The following activities will realistically be carried out in 2021:

- Development of methods to (i) augment result of mechanical characterisation from instrumented indentation test and (ii) reduce the indentations, by exploiting Electrical Contact Resistance method.
- Metrology for surface topography characterisation: participation to the CIRP sponsored interlaboratory comparison of the noise characteristics (to be rescheduled).
- Metrological characterisation of surface topography measuring instrument: investigation of field of view correlation and instrument's systematic error correction, exploiting big data analysis techniques.
- Development of artificial intelligence algorithms to identify and isolate surface topographical features.

Definition of machine learning procedures for quality control and improvement of manufacturing processes.

G - Sustainability

Within the "Sustainability" context, future developments for the year 2021 will include the enrichment of capability and performance assessment frameworks for manufacturing towards the circular economy. Among the well-known 6Rs of sustainable development, a particular focus will be given to the impact of re-manufacturing, repair and recycling on environmental, process cost and efficiency metrics. New environmental-conscious decision-support tools, in addition to those already published by the research group, are expected to be achieved by the end of the project. Moreover, regarding the sustainability assessment of unit-processes, the methodology for the comparison of conventional and innovative manufacturing approaches will be applied to industrial mockups and case studies.

H - Technological change

In 2021 each line of research will object of further development. In particular, case studies (like the ones conducted in the projects for INAPP, the National School of Public Administration (SNA) and the research programs on the digital transformation of tourism and the automotive sector) will allow to go more in depth on how digital competencies get integrated and combined with legacy competencies (both at the firm-level and the employee-level). The goal is also to develop original and novel learning material like pedagogical case studies that can be used in M.Sc. programs and executive and specializing Master programs. In this way, the Dipartimenti di Eccellenza program will allow to develop unique and original material for advanced education on the topic of digital transformation and how to combine "man" and "machine" in the current production and organizational systems

I - Algorithms and their influence on decision making processes

In 2021, a strong focus on major themes on operations management and logistics will be induced by the arrival in the Department of Prof. Perboli. The renewed presence of Prof. T'kindt as Visiting Professor will continue to be focused on bilevel scheduling problems and on the integration of machine learning technologies into optimization methods for machine scheduling. The integration of combinatorial optimization and combinatorial design for cyclic balanced nurse rostering will be explored. On the applied level, the activity on operating rooms scheduling will be prosecuted.

L - Algorithms for complex production systems and supply chain

For production system analysis, next year research will focus on the server allocation problem, by including the possibility to have non-identical machines at each stage of the production line, and on scheduling in complex systems (e.g., open shops). Moreover, to further study the generation and real-time update of digital twins of production systems, effort will be made to develop methods to generate and update the digital twins from data collected by sensors placed on the production system. Instead, research on eco-industrial parks will investigate the methods to formalize data collected simultaneously by the operators and the IT systems to detect, represent, and automatically updated the activities (both value-added and non-value-added activities) of the production systems under economic and environmental dimensions. These formalization methods will be used to deepen the link between network and operational level of firms involved in Eco-Industrial Parks.

M - Economic perspective

The research on the economic perspective in the course of 2021 will further focus on the main guidelines approached in 2020 and will be mostly finalized to end on going research but also start new ones. In particular, a substantial effort will be devoted in expanding the impact analysis on new digital highways on firm innovation incentives, firm productivity and local growth. For this aim, the group is already starting collecting fresh new data in collaboration with other University, such as LUISS and University of Tor Vergata, Rome. The research will also be continued and expanded on the collection of firm-level patents on Industry 4.0 technologies and the analysis of case studies on Additive manufacturing.

N - Legal perspective

The research on the legal perspective in the course of 2021 will further focus on the main guidelines approached in 2020 (i.e., AI regulation, data security and cybersecurity, 3D Printing product liability and IP protection and impact of AI on corporate governance), benefiting from the synergies with H2020 CyberSec4Europe (2019-2022) and with Relevant Research of National Interest on "Governance of/through Big Data: Challenges for European law". We also aim at exploring the potential for further synergies with new and existing projects and identifying lines of research that may attract interest (and possible funding) at national and international level.