WHITE PAPER AP7
FACTORY OF THE FUTURE

EXECUTIVE SUMMARY

This white-paper reflects the CNR vision of the Factory of the Future and is conceived to provide a reference model to support the transformation of National and European manufacturing sectors, which need to undergo innovation-driven evolutions to maintain competitiveness while facing mega-challenges, such as globalization, resource scarcity in the global knowledge society. It collects the contribution of all the CNR Institutes working on this thematic area, namely: IEIIT, IASI, IMEM, ICAR, ISTI, IMATI, ISTC, IMAMOTER, IIT, IAC, IFAC; IREA, STIIMA.

1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

The Manufacturing sector is a fundamental pillar for the technological progress and the economic and social prosperity of modern countries. Italy plays a primary role in Europe and can rely upon unique resources to preserve and enhance its competitiveness in manufacturing. In Italy, the manufacturing sector includes 427 thousand companies employing around 4 million people, generating a turnover of 871 billion euro and an added value of about 225 billion, ranking in sixth place in the world rankings for the weight of the sector in the economy. It should be noted that among the top ten European Manufacturing Regions by number of employees and number of companies, there are four Italian Regions: Lombardy, Emilia Romagna, Veneto and Piedmont.

Italy concretely represents a set of optimal environmental conditions difficultly replicable in other contexts, as its industrial vocation, the ability to create products that combine design, technology, personalization and thanks to the great tradition in the machinery and automation sectors. Representing a reference point means for the CNR to successfully conduct research and innovation that leads to the enhancement of the sectors in which the country can best express its potential.

In the Manufacturing field, the Factory represents the reference paradigm and therefore it makes sense to develop activities oriented to the evolution of this paradigm in which different enabling technologies also linked to the digitalization of manufacturing are proposed as a way for innovation. The role of IoT (Internet of Things) tools, Cyber-Physical Systems (CPS), digital manufacturing, big data analytics, advanced sensors and intelligent sensor networks is crucial to improve the efficiency and sustainability of products, processes and production systems, towards a circular economy vision. Industry 4.0 is the next developmental stage in the organisation of the manufacturing value chain, with ICT-based systems playing a major role, mainly by creating a virtual copy of the physical world and facilitating decentralised structures through cooperating CPS.

At the same time, the required industrial evolution must run along different lines that are complementary to each other such as: advanced production technologies; mechatronic systems; systems for the integrated modeling and simulation of products and processes; technologies for product customization, for the enhancement of people in factories, for environmental sustainability, for the management of the product End of Life (EoL), for the development of innovative materials and for the strategies and management of new production processes.

In this context, the driving aspects in the development of the aforementioned enabling technologies for the Factory of the Future are: the implementation of digital technologies, the adoption of both a technology push -market pull approach, the definition of open and participatory standards taking into account the specific Italian context mainly characterized by small and medium-sized companies, the focus of digital technologies towards the strategies for the circular economy and for product customization as well as the centrality of man in manufacturing production processes.

The role of the CNR in supporting the Italian manufacturing sector has been explained over the years by promoting research and innovation with participation in significant initiatives both at Italian and at European level

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

The main activities of the CNR's Institutes on the topics are described in the following, as well as the main involved Institutes. Such activities span over all the main industrial sectors (fashion goods, machinery, construction, agricultural machinery, food, automotive, aeronautic, …).

1. Systems for personalised production

The main research and innovation topics are related to different aspects of product development, including products to enhance consumer's health and well-being, towards the development of solutions and systems for the efficient production of personalized products with high added value, in order to promote the growth of the Made in Italy paradigm in Europe and worldwide. These systems should support a fast ramp-up and short configuration and re-configuration time to satisfy custom requirements, guaranteeing a high level of integration with clients and client specifications, and they will be characterized by new business models and agile and flexible supply chains.
In order to meet the increasing demand for product differentiation and customisation in terms of advanced features and smartness. the personalised production paradigm is shifting toward the adoption of novel technological approaches, such as hybrid processes and additive manufacturing. The combination of advanced manufacturing technologies with innovative approaches to the process monitoring and control, along with ICT solutions for the acquisition of the client's requirements, product configurators, advanced measuring systems, is leading to the development of new flexible and agile manufacturing models considering product modularization strategies, postponement and multi-decoupling points. The main addressed research topics are:

1.1 Innovative methodologies for product analysis and design

1.2 Digital Manufacturing tools and systems for Computational Design & Engineering, including methods for the integration of Computational Aided Design & Engineering

1.4 Process Planning for Additive Manufacturing

1.5 Advanced tools for the configuration and design of personalised solutions

1.6 Technologies for personalised production with high added value

1.7 Mini-factories. A model for re-organising the production and distribution chain.

2. Strategies, methods and tools for industrial sustainability

To respond to the growing complexity and competitiveness of the industrial scenario, new models and solutions have to be designed and developed, to improve both product and process sustainability, considering its whole life cycle and the future evolution of needs and availability of resources.
To tackle this challenge, new product and process design solutions are required, technologies and machine tools need to be improved, as well as an improvement in energy efficiency and waste reduction. They should be part of a more broader approach based on circular economy, with closed supply chains and coherent business models, exploiting all the knowledge-based tools and methodologies offered by the smart factory paradigm. The industrial actors should share information through the integration of machines, operators and factories, in order to improve their flexibility, reconfigurability and reactivity to the more and more dynamic requests of the markets.
The main research lines within this topic are:
2.1 Methods, tools and KPIs for the sustainability of the production activities

2.2 Methods for the analysis and the improvement of the sustainability of the extended factory

2.3 Technological solutions to improve energy efficiency and reduce waste

2.4 Innovative products

2.5 Methods and integrated tools for eco-design

2.6 Methods and tools for de-manufacturing systems with improved flexibility and their supply chains.

2.7 New business models and sustainable value chains

3*. Human centered factories*

Based on the specific challenge arising from the demographic and social trends and the needs of all categories of workers, the research activities are focused on the design and development of production systems that can host people and enhance their skills in order to give a contribution to the satisfaction and well-being of workers. Indeed, the factory of the future will increasingly face problems linked to ageing population that, reflecting itself in an extension of the working life, makes it necessary to enable people to carry out their job compatibly with the evolution and change of their cognitive and physical abilities. Addressing this issue requires a huge effort from both technological and organizational point of views. Therefore, the innovative factories will have to be increasingly inclusive, or strongly oriented to the involvement and participation of people (users, operators, managers) who will perform complex activities with high added value with the support of innovative tools and devices. As a result, people and machines will have to be able to cooperate synergistically, sharing activities in an efficient and safe way. The workplace will have to be redesigned on the basis of specific rules of ergonomics and organized according to adaptive work rhythms to provide an environment and working conditions appropriate to the different people, in order to allow them to operate productively regardless of their age, sex and physiological or pathological status. Similarly, the use of enabling technologies aimed at the digital representation of the factory promotes the integration at information and knowledge level. Hence, each person has to be considered a central element with respect to all the levels and dimensions defining the factory. In a context characterized by factories where products, processes and technologies evolve through articulated dynamics, a fundamental challenge is represented by the knowledge and the ability to interpret complex production phenomena and identify solutions based on experience. Therefore, it is essential to invest strategically also in the enabling technologies, such as VR/AR to support to support user-centered tasks such as operator training and maintenance support by means of visual, auditory, tactile feedback and interaction, as well as appropriate semantic and ontological representations of information and knowledge to support the formalization and reuse of such experiences.

Specific research topics are:

3.1 Innovative devices, systems and strategies for online security monitoring

3.2 Cyber Physical Systems (CPS) for safety and security in the Factory of the Future

3.3 Human-Computer Interaction (HCI) devices, tools and methodologies to manage context dependent information in production environments

3.4 Methodologies for ergonomical assessment and optimization

3.5 Tools for worker activities analysis

3.6 Innovative mechatronic devices – hardware, control architecture and sensors- for safe human-robot cooperation

4. High efficiency adaptive and evolutionary production systems

The research topic aims at developing both high efficiency production systems to minimize production costs and consumption of resources and energy, while improving productivity and product quality and a new generation of evolutionary production systems dynamically adaptable to the external changing conditions,

due to the fast evolution of technological processes and the frequent and sudden changes in demand, in terms of production mix and volumes required.

To achieve the abovementioned goal, several topics need to be addressed:

4.1 Advanced control systems and real-time optimization for production lines and systems: design and development of self-optimizing control systems in real time, through the adoption and extension of predictive and model-based control techniques on distributed architectures (DMPC), development of dynamic real-time optimization (DRTO), integration of hybrid control systems including decisions of a discrete and energy-aware nature, dynamic identification techniques for the optimization of distributed systems and industrial Cyber Physical Systems (CPS).

4.2 Industrial communication systems: high performance industrial wireless networks, Clock Synchronization Protocols, real time Ethernet, Modbus, CAN, CAN FD.

4.3 Formal Methods and Models for the Security of Industrial, Cyber Physical and Safety Critical Systems

4.4 Smart components, sensors and machines for adaptive and evolutive production: sensors (eg: x-ray detectors, magnetic based sensors and transducers), Real-time operating systems for multicore processors, real-time multicore scheduling and synchronization and resource management, monitoring, intelligent vision systems for quality control

4.5 Innovative production processes:

4.6 ICT Technologies for the interoperability, agility and servitization of the Factory of the Future: service-oriented architectures, interoperability, optimization methods for the extended factory, for the efficient and collaborative planning and scheduling of global production networks and their supply chains.

3. IMPACT

The Manufacturing sector significantly contributes to address the 'grand challenges' of the 21st century, promoting a smart, sustainable and inclusive growth, ultimately impacting on employment, wealth, health and ageing population, The manufacturing sector generates about 16% of European GDP and employs 20% of the population (30 million people in 230,000 companies, most of them small and medium-sized). Moreover, the industry supports the service sector. Not only it produces products and goods, necessary for its operation, but it also generates jobs in this sector thanks to the indirect employment (it is estimated that each job in the manufacturing industry generates the double in the service sector). In the European economy and also in the national one, the manufacturing sector represents the first sector for export (being responsible for more than 80% of European exports), it is the first sector for private investments in R&D (66%) [EFFRA], level of innovation and productivity growth.

Specifically, the Italian manufacturing sector generates a turnover of 871 billion euro and an added value of about 225 billion, ranking in sixth place in the world rankings for the weight of the sector in the economy.

For this reason, all countries interested in playing a leading role on the international scene and aiming at industrial independence have to invest in this sector. To accomplish this goal each country should address strategically its manufacturing activities according to its own resources and to the competitive dynamics which determine the international context.

The current international context is characterized by the growth of emerging economies, mostly Asiatic, which are able to offer products characterized by an increasing quality at a lower price compared to the one realized by mature economies. This is made possible by low labour costs, worse working conditions, by the availability of raw materials and by fewer environmental safety and IPRs regulations. Mature economies are therefore focusing their offer more and more on innovative technologies, personalized solutions, high added-value manufacturing, integrated product-process-system solutions.

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For each country, research is crucial to address its societal challenges and to successfully follow the innovation path leading to the valorisation of the sectors where the country can best express its potential. Therefore, considering the Italian and European manufacturing sector the following research and innovation priorities seem to be fundamental:

- a new systemic perspective on manufacturing, which considers the coevolution of products processes and systems;
- new cutting-edge technologies and processes to achieve high performance manufacturing (high quality and productivity);
- new advanced manufacturing systems supply chains and business models adaptive and highly integrated, to foster economic sustainability in the various manufacturing sectors in continuous evolution;
- new manufacturing technologies and systems to realize new products for the societal challenges;
- new technologies and solutions to valorise the central role of people and their unique competences;
- new approaches to guarantee a continuous improvement and innovation of the competences of the manufacturing;
- new technologies and solutions for the environmental sustainability of factories, which must use planet resources efficiently within a new manufacturing/de-manufacturing paradigm;
- new ways to effectively and efficiently integrate research and innovation.

In order to drive the change toward the most relevant priorities, it is necessary to lead strategically the research and innovation carried out by universities, research institutions, companies and other innovation actors in order to address them towards innovation goals and policies in an efficient and synergic way. It becomes therefore important for the research and industrial actors, as experts in frontier innovation and technologies, to take an active part in the road-mapping activities and in the definition of the research policies.

The role of the CNR in supporting the Italian manufacturing sector has been explained over the years by promoting research and innovation with participation in significant initiatives both at Italian and at European level such as:

- The launch of the "*Manufuture*" platform as an initiative to support the manufacturing sector at European level and participation in the High-Level Group of the platform itself;
- The guiding role in the establishment of EFFRA, the Public Private Partnership created by the European Commission on the manufacturing sector, and the definition of the roadmap and the Factories of the Future tenders activated within the relevant European framework;
- The central role in the establishment and growth of the Smart Factory Cluster within the national cluster promoted by MIUR, and the definition of the roadmap for companies in the Italian manufacturing sector, followed by the establishment of 7 working groups on strategic lines of intervention. Participation in cluster projects with a total value of 40 million euros.
- The direction of the "*Fabbrica del Futuro"* flag project, with important research initiatives aimed at increasing the competitiveness of Italian industry and in particular of "Made in Italy" in the global context. The project has a 12-millions euro loan and has involved CNR institutes, universities, research bodies and consortia, companies and consortia of companies.
- Coordination of the European LET'S2014 conference (Leading enabling Industrial technologies for European Renaissance), promoted by MIUR and MISE, which highlighted the most recent developments in terms of technologies enabling manufacturing and which represented a key event of the Italian Presidency semester.
- Coordination of the project "Innovative technologies and systems for the factory of the future and Made in Italy" which aims to promote the development of enabling technologies to increase the impact of innovative manufacturing solutions developed in recent international research projects, in optic of synergy and complementarity with the other national initiatives on newly launched manufacturing research.
- Participation in regional initiatives to support manufacturing, including the regional Lombard cluster AFIL with support activities for the definition of strategic lines for research and innovation.

- The direct participation of CNR Institutes in several dozen European research projects in the FOF (Factories of the Future), Robotics2020, SPIRE calls with the production of important industrial results in various technological areas.
- The coordination of the KIC EVCE proposal on Added Value Manufacturing

All these actions highlight the role of the CNR as a primary actor in the initiatives concerning manufacturing in the national and international scene. And they form the basis for defining the goals and objectives of this AP.

4. EMERGING RESEARCH CHALLENGES

The main emerging research challenges address the development of technological approaches merging materials, manufacturing, electronics and AI for the creation of new products, sensor fusion and integration of ICT and analytics to extract information from heterogeneous data sources.

5. CONCLUSIONS

The main objective of the "AP-Factory of the Future" is to expand and to promote research in the manufacturing industry and to represent a research hub in relation to the industrial world. The AP organizes research themes around the concept of Factory, allowing it to be dealt with a pervasive and unitary way all the salient aspects involved. The factory is defined as the coherent set of enabling technologies, processes and products that dynamically evolve over time to follow market needs and new production logic.
Within the organization of research topics, the definition of the main areas of strategic expertise that can contribute to the scientific-technological growth of the manufacturing industry, bringing the research world closer to the industrial needs, is also of significant importance. Most of the projects presented in the previous paragraph are organised to cope with this mission.

The research activities are aggregated in four main area:

1. Systems for personalised production
2. Strategies, methods and tools for industrial sustainability
3. Human cantered factories
4. High efficiency adaptive and evolutionary production systems

In order to facilitate the identification of these areas of expertise, it has been associated a series of characteristics that are fundamental for the idea of factory of the future.

1. Intelligent and adaptive: in order to interpret the information and implement autonomously adaptive and repair strategies, modifying its performance, its methods and operating dynamics, in various production fields.
2. Sustainable along its life cycle: operating in full compliance with energy consumption and emissions constraints, as well as from an economic and social point of view
3. Built around people: being strongly oriented towards the involvement and participation of people at various level who can perform complex activities with high added value with the support of innovative tools and devices.
4. Evolutive compared to products-processes: for coping with rapidly evolving demand and production and de-production technologies enabling the reaction to product and process change over time.

PROJECT AREA 7: FACTORY OF THE FUTURE

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