ISSN 2386-5414
e-ISSN: 2340-8391

Review | Revisión

Approaches and Technologies for the Human-Centered Industry 5.0. | Enfoques y tecnologías para la industria 5.0 centrada en el ser humano.

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Recieved:: February 27, 2023 | Accepted: May 10, 2023 | Published: June 29, 2023
https://doi.org/10.25267/P56-IDJ.2023.i3.05

ABSTRACT

A little less than a decade after the emergence of Industry 4.0 in the industrial world, the new paradigm 5.0 is gaining ground, which is simultaneously reflected in the definition of a smart society. In fact, we are witnessing an innovative transition that defines the pace of technological, but also economic and social change. Starting from the innovations of the fourth industrial revolution and from the study of reference guidelines of European Commission (2021) Industry 5.0 "repositions" technologies completely at the service of people and the whole of humanity. The research aims to identify and explore the points of contact and implementations arising from the transition from paradigm 4.0 to the human-centric approach 5.0. Through a comparative analysis of case studies and best practices in the industrial field it is possible to frame and define the future scenarios of manufacturing that see human and machine synchronized and synergistically working together to improve the efficiency of production.

Keywords: digital transformation; enabling technologies; User Centered Design; Industry 5.0; Human factors; Industrial Design.

Resumen

Poco menos de una década después de la aparición de la Industria 4.0 en el mundo industrial, gana terreno el nuevo paradigma 5.0, que se refleja simultáneamente en la definición de una sociedad inteligente. De hecho, asistimos a una transición innovadora que define el ritmo del cambio tecnológico, pero también económico y social. A partir de las innovaciones de la cuarta revolución industrial y del estudio de las directrices de referencia de la Comisión Europea (2021), la Industria 5.0 "reposiciona" completamente las tecnologías al servicio de las personas y de toda la humanidad. La investigación pretende identificar y explorar los puntos de contacto y las implementaciones derivadas de la transición del paradigma 4.0 al enfoque centrado en el ser humano 5.0. A través de un análisis comparativo de estudios de casos y mejores prácticas en el ámbito industrial es posible enmarcar y definir los escenarios futuros de la fabricación que ven al ser humano y a la máquina trabajando sincronizados y sinérgicamente para mejorar la eficiencia de la producción.

Keywords: Transformación digital; Tecnologías facilitadoras; Diseño Centrado en el Usuario; Industria 5.0; Factores humanos; Diseño Industrial

Introduction

What we are living is certainly the new era of manufacturing in which we have come to the full awareness of how enabling technologies are the basis of the competitiveness of companies on the international market and of the improvement in terms of productivity.

Through the widespread diffusion of innovation and thanks to the continuous updating of production technologies, the factory is experiencing a renewal with positive effects on the health of production operators. (Formati et al., 2021)

Starting from the study of the document entitled "Industry 5.0 - Towards a sustainable, human-centric and resilient European industry" (European Commission, 2021) it is possible to highlight the main axes that have been identified by the European Union for the definition of Industry 5.0: human-centricity, sustainability and resilience.

In detail, from the transformation of industrial spaces into safe and inclusive environments and through the satisfaction of needs, we are witnessing a change in the role of the user "positioned" at the center of production processes to implement levels of psycho-physical well-being. Moreover, sustainable evolution represents the further pillar of the new industrial context through the use of renewable sources, the reuse of energy and the reduction of energy waste. Finally, another founding element of Industry 5.0 (European Commission, 2021) is represented by resilience, referring to the need to develop industrial contexts increasingly robust and adaptive to new needs. Industry 5.0 is not necessarily to be understood as an evolutionary continuation of its predecessor 4.0, but as an extension of the main features and essential factors designed to place future industry in the new society. (Xu et al., 2021)

Also, in the previously mentioned document, the European Commission identified the six main technological axes 5.0: personalized human-computer interaction, technologies inspired by nature and intelligent materials, digital twin, technologies for data transmission, storage and analysis, artificial intelligence and finally technologies for energy efficiency, renewable energy, energy storage and autonomy. In the past, the interaction between the user and the technologies has been analyzed from different perspectives, addressing the capabilities, limitations of the operator and machines to define the criteria for automating process tasks and completely replacing industrial operators (Winter et al., 2014).

The European Commission (2020) defines the technologies that support the concept of Industry 5.0: human-centric solutions and human-machine-interaction; bio-inspired technologies and smart materials; real time based digital twins and simulation; cyber safe data transmission, storage, and analysis technologies; artificial Intelligence; and technologies for energy efficiency and trustworthy autonomy.

Starting from the knowledge of such “tools”, as also argued by Xu et al. (2021), some of the 4.0 technologies will help to achieve the social and economic goals of Industry 5.0. It will increasingly be used in the new Society to generate the new scenarios of innovation with the cooperation between humans, machines and technologies.

Industrial Evolution in Society 5.0

In today’s industrial contexts, technologies, which have become accessible to all, are spreading at such a speed that the same transformations and innovations are taking place more rapidly than previously. Successive industrial revolutions have actually significantly transformed society by “altering” not only production systems, but also interactions between individuals and with their surroundings (Schwab, 2019).

As a matter of fact, Industry 4.0 was born as an evolution of the previous industrial revolutions: (i) the introduction of water and steam power to mechanize production, (ii) electricity for mass production and (iii) information and digital technology to increase automation levels by making use of electronic systems and Information Technology. The innovation pursues the strategy to generate products and services with radically new meaning and it represents the determining factor in the development of society and the advanced economies of nations.

With reference to production, Industry 4.0 has generated the increase in the product and services quality, together with the promotion of new business models, to fill the gaps about the current state of digitalization and in the competitive market perspective offered by new technologies. In particular, Industry 4.0 has “rethought” factories through the use of digital, as well as reconsidering the design approach and monitoring the production process in real time (Laudante & Caputo, 2016).

On the basis of the literature review, it is possible to assert now that Industry 4.0 has entered an advanced stage of maturity after several years of development with reference to some technological factors. This does not mean that it is an outdated paradigm. On the contrary, it represents the natural step in which the new declination of the human-technology relationship is highlighted through the innovative Human Technology-Oriented approach. This approach triggers the futuristic vision of a new evolutionary stage in which human and machine reconcile and work in perfect symbiosis with each other (Longo et al., 2020).

Industry 5.0 represents the further technological transition that introduces the new role of modern industry in society. This new vision explains how technology succeeds in changing our lives and how technological innovations are capable of shaping the economic, social, cultural, and human scenarios in which we operate (Schwab, 2016).

Differently from Industry 4.0, considered as “Smart Manufacturing for the Future” (Demir et al., 2019), which mainly pursues the purpose of increasing productivity and reaching mass production using innovative technologies, Industry 5.0 will bring new challenges in human-machine interaction. This provides analysis and research in the area of human factors, recognizing in human welfare the main objective to achieve sustainability and social welfare and not only productivity.

It is more of a cultural revolution characterized by the inclusion of the resolution of production but also socio-environmental problems through the use of technologies considering people and the environment. This aims to ensure that the needs of current generations do not compromise those of future generations.

It is increasingly possible that Industry 5.0 will generate unprecedented innovation in human-machine interaction (HMI) starting from the increasing presence of machines in people’s daily lives and the consequent demand for specific skills in the field of HMI and more generally in the computational analysis of human factors (Nahavandi, 2019).

Considering that technological progress cannot disregard the development of economic and social welfare, technology is understood as a means for change and hopefully the improvement of the entire society.

In fact, Industry 5.0 and Society 5.0 represent two related concepts that define in parallel the new paradigm not limited to manufacturing. This highlights the emergence of new broader societal challenges in which advanced technologies such as robots, artificial intelligence and augmented reality are actively employed in everyday life, generically to improve people's quality of life (European Commission, 2021).

The Society 5.0 Concept – introduced by the Japanese government back in 2016 – represents a vision of a future society guided by scientific and technological innovation. "Through an initiative merging the physical space (real world) and cyberspace by leveraging ICT to its fullest, we are proposing an ideal form of our future society: a Super-Smart Society that will bring wealth to the people". The series of initiatives geared toward realizing this ideal society are now being further deepened and intensively promoted as "Society 5.0" (European Commission, 2021).

Society 5.0 is defined as the "Society of Intelligence" (Salgues, 2018), in which physical space and cyberspace are strongly integrated and in which innovation in science and technology occupies a fundamental role. It thus represents the new business model that focuses primarily on "intelligent" human-machine collaboration and therefore on the full synergy between human and artificial intelligence through the definition of new organizational models and acquisition of increasingly targeted skills.

The constant threat of human labor being replaced by machines will be replaced by increased sensitivity and attention to human well-being and the "protection" of one's mental and creative abilities, towards the promotion of a "Super Smart Society". In this context, advanced technologies define the profile of a new high-performance, "super-intelligent" and "human-centric" society through the promotion of innovation. The visionary idea is to use the new technologies in an intelligent, inclusive and responsible way aiming to improve living conditions, also in terms of health and safety in the workplace, as well as processes and products.

It will be appropriate to design the relationships between technologies, society and users in order to experiment with new ways of knowledge transfer through contemporary and innovative techniques and tools (Buono & Giugliano, 2021).

One of the characterizing factors of Industry 5.0 is represented by the human-centric approach in industry that puts human needs and requirements at the center of the process for defining the increased efficiency and production added value through the reduction of waste and associated costs. (H-UTokyo Lab., 2020)

In particular, the connection between human creativity and machine efficiency will guarantee the added value in new productions. It moves from a strongly machine-centric approach to a human-centric oriented "vision" that will increasingly take shape with the definition of systems that are more personalized and closer to the real needs of the user.

In accordance with Doyle-Kent & Kopacek (2019), each product 5.0 will be based on the real individual user needs by putting new technologies at the service of the population. This will make production more lean, automated, digital and data-driven by endowing the designer with more freedom. Realizing new products requires what can be called the "human touch" through human involvement and engagement, as reported by Østergaard (2018). He defines this process as a new mode of customization through the enhancement of creativity and the spirit of resilience as the main indications provided by the new 5.0 model (Ruffinoni, 2020).

In reference to personalization, a key point of the new "collaborative" industry, Maddikunta et al. (2021) refer to the concept of "'hyper personalization". This model applies cutting-edge technologies to provide more specific products, services, and content to each user so that the integration of human intelligence with robots helps personalize production with minimal cost and maximum precision based on consumer needs and market changes.

The new anthropocentric approach in Industry 5.0

The industrialization process has led to the widespread use of machines that have steadily increased in number and complexity over time. In such contexts, the user and the machine interact through interactive tools designed to improve machine performance and to facilitate operator management and control. New forms of interaction with technology are being configured that require the user to have greater capacity and cognitive ability.

Since the beginning of industrialization, machine capabilities have increased and human control of processes has evolved from simple, with mechanization, to cognitive, with computerization, and emotional, with automation (Pacaux-Lemoine et al., 2017).

The transition to Industry 4.0 has seen the rise of cyber-physical systems and the introduction of digital technologies, technical, organizational and design changes, involving new forms of human-machine interaction and a new balance between physical and cognitive load. Overcoming these challenges will require the application of new user-centred design approaches that take into account physical, cognitive and sensory capabilities (Kadir & Broberg, 2021), putting the worker's needs and requirements at the center of the process. This moves from a technology-oriented to a human-centred approach (Xu et al., 2021).

The computational thinking process (Wing, 2006), i.e. the mental process of solving problems of various kinds through the planning of strategies and execution logic, has driven the configuration of technologies and information technology over the last few decades. This process has made it possible to exploit the potential of machines as objects capable of compensating for human skills or inaccuracies. However, this approach implies inherent problems in the design of solutions to which the user must necessarily adapt. Conversely, anthropocentric design, and hence the study of human-machine interaction, aims to adapt product requirements and specifications to users. From these scenarios, the need for the integration of different disciplines emerges to configure new, effective and efficient solutions that can adapt and fulfil the user's needs.

In fact, according to the European Commission (2021), the important prerequisite for Industry 5.0 is that technology should serve people and therefore be adapted to the needs and diversity of workers in the industry. Therefore, it is necessary to change the design paradigm and place the focus on human factors and ergonomics requirements (Kadir & Broberg, 2021), to achieve the sustainable implementation of enabling technologies and promote the well-being of workers.

Based on these factors, it will be possible to design flexible and adaptable places, usable and on a human scale, according to a user-centered methodological approach – methodology sanctioned with ISO 9241-210:2019 "Ergonomics of human-system interaction" – in which the user becomes the center of the design phases. A crucial aspect in the design of systems and solutions introduced by Industry 4.0 has concerned the interface between people and the set of technologies implemented. This system has become increasingly complex and articulated to the point of making the concept of human-machine interface obsolete and reductive.

In the Factory of the Future, people no longer operate and interact with a single machine, but with a network of cyber-physical systems. These systems of physical and computational components are decentralized, dynamic, open, and context-sensitive, constantly evolving, and which are intertwined with the mental and social worlds of the users, so much so that they are defined as cyber-physical-social (Assolombarda, 2020).

In this context, production operators acquire autonomy, and the working environment becomes more inclusive. To achieve this, the operators must be involved in the design and implementation of new enabling technologies. For example, the Factory 2Fit project aims to empower and involve operators in a connected industrial environment who are given greater influence and responsibility in shaping the production process, through virtual means. Early results from this project indicate a positive impact on productivity and worker well-being. Initiatives such as these make it possible to link increasing automation with human skills, thus strengthening the human-centered approach (European Commission, 2021).

The automation does not only concern the introduction of new intelligent machines able to interact with the environment, with other machines or with the operators, but it involves the radical change in the way of thinking about processes and workflows. In this way, it's possible envisage new ways of collaboration between human and machine and reconfiguring the activities of the Smart Factory (Leoni, 2019).

The design guided by the needs and physical-perceptual characteristics of the operators acquires relevance in the definition of working environments, defining the transition of design from technology-oriented to human-oriented. In the design phases, the focus is no longer exclusively on functional requirements and what is technically possible, but on the needs of the user. He is no longer forced to adapt the way he or she works to the product, but the latter is designed according to work preferences (Flaspöler et al., 2006).

A human-centered production system is characterized by the planning and implementation of the production process, where the user is in control of the process and technologies, encouraging the use of human skills (Charles et al., 1990). An example of a human-centric workstation, anticipated already between 2018 and 2019 by the company Festo, can be identified in the "BionicWorkplace" system. This solution proposes a new working context of human-robot collaboration, where connection and safety guarantee new ways of working.

The workstation is ergonomically designed and all elements, right down to the lighting, can be configured, customized and adapted to suit the user. At the center of the production operator's field of vision is a projection screen that provides all the relevant information, dynamically displaying the content according to the activity in progress. Surrounding it, there are sensors and camera systems that constantly record the positions of the operator, components and tools. In this way, the user can interact directly with the "BionicCobot" and control it using movement, touch or voice command. The system recognizes operators and movements through the use of innovative clothing. By configuring intelligent workplaces that foster learning through the introduction of multifunctional tools, the collaboration between humans and machines will become increasingly intuitive, simple and efficient in the future.

Recent developments include the introduction of automation systems featuring technologies such as artificial intelligence, natural language processing, predictive analytics and robotics that define radical innovation at the workplace. Optimizing human-machine interactions will capitalize on the added value that production workers bring to the factory by developing innovative human-centered technologies. Industry 5.0 can support and empower, rather than replace, workers (European Commission, 2021) and technologies such as artificial intelligence will be able to redesign production activities where the added value will come from the operator's intellectual capabilities (Matsushima, 2017).

Indeed, according to Daugherty & James Wilson (2018), artificial intelligence frees up time, creativity and human capital, while work activities become less automatic. According to this view, technologies improve operator capabilities and support their activities. Examples of technologies that increase operators' performance are exoskeletons to support physical activities; augmented reality to transfer knowledge and increase cognitive abilities; wearable technologies to improve health through monitoring physiological conditions (Fantini et al., 2018).

The use of new wearable devices, integrated with virtual and augmented reality technologies, allows the development of applications or "scenarios" to support naturally and effectively innovative services useful to provide product, process and production progress information. This constitutes the technological basis for the development of digital environments. In such scenarios, every piece of information is at hand and every operation can be carried out in an optimized way, to reduce time and costs (Favetto et al., 2018).

However, the user is often regarded as one of the most unpredictable components of any system and an important, usually limiting, design parameter. Environments and products are used by users with multiple physical and dimensional characteristics and wide variations in strength and flexibility. The importance of investigating these variables has led manufacturers to consider user issues earlier in the design process. In fact, in many application areas, there is a strong need to model the physical elements of humans together with models of workplaces and equipment (Morrissey, 1998). The user governs and manages the production processes, and he must be able to monitor and interact with different machinery located within the factory. In order to do this, it is necessary to introduce a simple level of interaction and integrated involvement with the surrounding environment, using innovative and wearable devices. During work activities, the user must be able to interact with the industrial context, the robots and the machines simply and intuitively, through hands, arms, eyes, voice.

Numerous research breakthroughs in neurophysiological and cognitive sciences have spurred a wave of research aimed at effectively linking human and mechanical intelligence capabilities, as well as matter and nature to access intelligence for the benefit of humanity. "NextMind", unveiled at CES 2020, is the world's first brain-sensing device that simultaneously enables the control of augmented reality or virtual reality viewers. The device sits at the back of the head and attaches to any AR/VR device, allowing interaction with virtual environments directly with brain control. The device has a control system that captures neurophysiological signals and transforms them into data to create real-time neuro-control capabilities. Artificial intelligence-based technologies are incorporated to decode user intent and translate neural signals into digital commands, transmitted via Bluetooth technology.

According to Lu et al. (2021) through natural human-machine communications, including empathic understanding, anthropocentric production will become possible, converting current optimization practices oriented towards production control to the benefit of user well-being. This transition towards flexible collaboration will bring new challenges and opportunities to ensure increased production and worker well-being. Adaptive and reconfigurable systems with real-time data processing capabilities will be needed to address ergonomic issues while ensuring productivity in human-machine collaboration (Lu et al., 2021). Research on the intersection of Industry 4.0 and human factors has grown steadily, leading to numerous experiments exploring new technologies in highly digitized work systems.

The Industry 4.0 paradigm shift represented by the innovations made in the industrial sector and the effects on social and shared wellbeing. It configures the new scenario for the near future characterized by Human-technology oriented models and design approaches. It is therefore essential to imagine that the new generation of digital and interactive tools will have to represent the theoretical and practical changes of this mutation, where technology supports and adapts to the user, reconfiguring his skills.

In such a scenario, the concept of Operator 4.0 is born, describing a futuristic vision of intelligent and skilled workers doing the job, aided by machines and digital technological tools. Such an Operator can fully utilize digital capabilities and capitalize on emerging opportunities in Industry 4.0 enabled factories (Kadir & Broberg, 2021).

Enabling technologies for Operator 4.0

The new scenario of Industry 5.0 addresses the impact of technologies on users-operators and the connections between design and future industrial systems. As mentioned, Industry 5.0 implements the Industry 4.0 paradigm by placing research and innovation as pivotal factors to generate a network of sustainable industries, based on founding elements such as the centrality of the user, sustainability and resilience.

In this context the Operator 4.0 is born, as Taylor et al. (2020) argue, that will move from "operator" to "decision-maker", working with digitized and automated production systems and using creativity to solve unexpected and unforeseen challenges. Following these futuristic visions, Romero et al. (2018) highlight future operators will need to be able to manage different work situations and complex interactions. Therefore, they need to receive the right information and organized knowledge to fit their cognitive processes. Similarly, Peruzzini et al. (2019) consider the needs of Operator 4.0 as fundamental by adopting the human-centered approach for integrating human factors into work systems (Kadir & Broberg, 2021). The Operator 4.0 plays a key role in the factory of the future where technologies implement its capabilities and improve the tasks performed (Fantini et al., 2018). Understood as a decision-maker and problem-shooter, the intervention of the Operator 4.0 is developed through synergy with artificial systems along all steps of the production process, from task understanding, to decision-making, to production performance (Emmanouilidis, 2019). Traditional automation systems are unable to withstand the requirements of flexibility and adaptability needed by the factories of the future. So, efforts are being made to overcome the limitations of technologies from the perspective of perception, learning and planning. Through advanced communication and adaptive control technologies, it will be possible to support human-computer interaction systems and software for connecting physical-digital realities to enhance human performance. The evolution of Industry 4.0 and the development of 4.0 technologies in the areas of Internet of Things (IoT), Artificial Intelligence (AI) and Robotics have led to the creation of Cyber Physical Systems (CPS) managed by adaptive control systems and increasingly advanced IoT systems. The new frontier is CPS that is designed to implement human-machine interactions and physical-virtual connection tools to build increasingly sustainable and human-centric plants. The Operator 4.0 can implement its capabilities becoming more and more "intelligent" with the help of enabling technologies such as Collaborative Robotics, Big Data Analytics and Augmented Reality (AR).

Collaborative Robotics will be characterized by cobots capable of performing different types of tasks and actions in direct collaboration with the intelligent operator thanks to the presence of interactive, intuitive and easily programmable technologies. This will ensure significant benefits to the industrial world such as space optimization, cost reduction, increased productivity and psychophysical well-being of the operator. In the physical human-robot interaction, factors related to the perception of the environment and the "prediction" of the human operator are requirements that the collaborative robot must acquire in order to collaborate safely with the user.

The project "Mental Health promotion of cobot Workers in Industry 4.0" (MindBot) aims to improve the psychophysical conditions of the user-worker during the performance of work activities, adopting collaborative robots in production lines. The purpose is to create collaborative environments and workstations able to enhance the social and empathic aspects in the new industrial context.

Another enabling technology of the new industrial scenario 5.0 is Augmented Reality, which – as the Robotics – aims to improve workspaces and make them “smart” in synergy with the figure of the new operator and to transfer information from digital devices to the user in an adaptive and interactive way.

In addition, Augmented Reality offers the opportunity to connect the human-machine interface to IoT applications and production resources. This allows that the user-operator receives instant alerts on processes and smart production machines to optimize decision-making processes (Gorecky et al., 2014).

An application example of AR technology for plant maintenance is the Utility Hera system that allows the decrease of unplanned downtime, reducing the management and maintenance costs that are considerably heavy and therefore considered as unfulfilled production. Unplanned system downtime can be caused by different factors such as: hardware failures, unexpected absence of the production operator or inaccurate fault diagnostics. In fact, by focusing on such digitalization, companies will be able to increase the efficiency and competitiveness of their plants, improving manufacturing processes.

In the new 5.0 scenario, Big Data Analytics will govern an enormous amount of information moving from physical space to cyberspace. In cyberspace, Big Data is analyzed by Artificial Intelligence and the results of the analysis are returned to users in physical space (Pu et al., 2020). Big Data collection and management solutions in a 5.0 perspective will allow obtaining useful information for the definition of Key Performance Indicators (KPIs) parameters for the analysis and evaluation of costs, productivity and status of system outputs.

The described technologies will facilitate the work of production operators by offering the possibility to better understand the performance of plants and industrial processes, as well as to effectively monitor KPIs over long periods of time and activities and to receive immediate feedback from predictive analysis. This allows the production operator to detect problems to prevent system failures and to investigate causes directly from the workstations to optimize performance and make continuous and immediate changes (Zanella et al., 2017).

Thanks also to IoT and connected systems, the possibility of benefiting from large amounts of available data will allow greater learning in a short time and will ensure increasingly innovative and applicable solutions in the factory of the future (Aquilani, 2020).

In fact, together with AI and IoT, Big Data Analytics represent the enabling technologies that will lead the transition from Industry 4.0 to Society 5.0 and provide innovative solutions to improve the psychophysical conditions of users (Sharp, 2020).

Future scenarios for the Human-Centric factory 5.0

The industrial landscape is evolving towards the human-centric vision introduced by the Industry 4.0 paradigm, in the direction of Industry 5.0, adopting technological solutions and systems designed for Operator 4.0, defining future scenarios in factories (Longo et al., 2020).

Work modalities 5.0 imply the acquisition and the introduction of new skills that are able to elaborate and to define innovative solutions to interact with the surrounding environment.

Bianchi (2018) with the concept of “augmented intelligence”, between artificial intelligence and human intelligence,

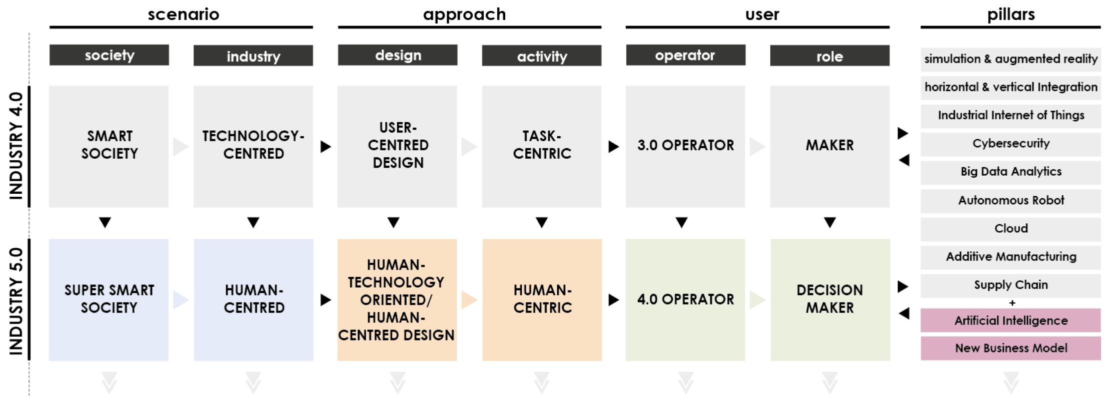

Figura 8. Graphic schematization of the three macro-areas involved in the transition from Industry 4.0 to Industry 5.0 that are classified into: transformation of the social and industrial scenario, new paradigm of anthropocentric design of the factory of the future and new role of the Operator 4.0.

highlights the increase in the degree of interactivity between human and machine, in the perspective of multiplicative perception and not replacement of human capabilities (Bianchi, 2018).

Starting from the analysis of the production scenario, the three macro-areas most involved in this new "revolution" have been identified: (I) the transformation of the social and industrial scenario, (II) the new paradigm for the anthropocentric design of the factory of the future and (III) the new role of the production operator (see Figure 1).

Starting from the configuration of the Super-Smart Society – and therefore from the birth of a hyper-connected and super-intelligent society – industrial spaces will also evolve where, through the human-centric design approach supported by enabling technologies, the figure of the Operator 4.0 will be consolidated as a user connected to the surrounding environment. The identified tools analyze the main ergonomic factors considering the operator at the center of production systems.

Figure 1 describes the main transformations from Industry 4.0 to Industry 5.0. In particular, the reference scenario from society to industry was analyzed. The new approach to the design and definition of user activities was highlighted, and finally, the role of the new Industry 4.0 operator in the industrial sector.

Therefore, the diagram shows a summary of the carried-out research activity, highlighting the agents involved and the human-centric work activities of the future. In particular, the new factors of Industry 5.0 are outlined as added value of industry and society. In this scenario, the operators will have the management of processes and the technologies will become tools to serve the user-operator. The human-centric perspective illustrates the evolution of the figure of the Operator 4.0 defined as a hybrid agent born from the symbiotic relationship between human and machine, an intelligent and experienced operator who performs tasks (Romero et al., 2016) outlined according to specific physical-perceptual characteristics, increasing their capabilities and skills. This new human-centric model provides the evolution of aspects to be considered in the design of future factories.

Industry 5.0 develops with the growing awareness of the value of the human-machine symbiosis in industry (Longo et al., 2020) and from this understanding it will be possible to define the anthropocentric factory of the future as a "collaborative" industry. In fact, from the synthesis of Maddikunta et al., (2021) of the different definitions of Industry 5.0, considered as a phenomenon still in the process of change and definition, it is possible to highlight how the human at the center of the process is the constant factor for the configuration of the intelligent, flexible and hyperconnected model 5.0.

Conclusions

The aim of this study has been to investigate the evolution of the manufacturing system by highlighting the transition from the 4.0 paradigm to the new Industry 5.0. This represents the technological, operational and cooperative vision and places research and innovation at the service of the transition to sustainable, human-centered and resilient industry. Through the application cases analyzed, the development of new tools and the identification of new needs, the study outlines the characteristics needed for user-centered factories of the future.

The relationship between users and technologies is constantly evolving and it sees the emergence of the centrality of human who "uses" technologies on the basis of emerging needs in the industrial, social and environmental landscape.

The implementations resulting from the transition from the paradigm 4.0 to the human-centric 5.0 approach may define the future scenarios of manufacturing where the human-machine symbiosis will improve the efficiency of production.

This study also outlines the new figure of the Operator 4.0 through developments and changes in the workforce and the description of future scenarios to be addressed in manufacturing systems with particular attention to the symbiotic relationships between new robotic systems and users. Therefore, the paper illustrates the factors present in the current context in which the radical diffusion of new technologies – in particular the proliferation of robotic systems and artificial intelligence – is only in its initial phase and it suggests directions for future research in the field of human-robot interaction. This research also shows how the scientific community is particularly attentive to the human-centric evolution in the manufacturing processes 5.0.

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Funding source / Fuente de financiación

This work has not received any funding. / Este trabajo no ha recibido ninguna fuente de financiación

Vontribution by authors /Contribución de autores

Giovanna Giugliano: Conceptualization, Methodology, Investigation, Writing- Original draft preparation, visualization/data presentation; Elena Laudante: Conceptualization, Methodology, Investigation, Writing- Original draft preparation, Writing- Reviewing and Editing; Fabrizio Formati: Conceptualization, Investigation, Writing- Original draft preparation; Mario Buono: Methodology, Investigation, Writing-Original draft preparation, Supervision, Validation.

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