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Design, space management and work tools: enhancing human work in transition to Industry 4.0

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Abstract | Industry 4.0 is a process that has a major impact on production methods and the organization of industrial work systems. With the spread of enabling technologies, workers begin to engage in new types of relationships with intelligent machines. In particular, collaborative robotics (cobots) is identified as an interesting case study to initiate a "human-machine hybrid" design process. Through research based on interviews, questionnaires and field observations, this study aims to define the three main challenges in the design of cobots, assuming the need to reaffirm the importance of a human-centred approach in the smart factory of the future.

KEYWORDS | INDUSTRY 4.0, HUMAN-MACHINE INTERACTION, COLLABORATIVE ROBOTICS

1. Industry 4.0: cooperation between machines, production department and workers

Industry 4.0 represents a major transformation process which involves a technological leap both in the use of computer science and in the field of industrial automation (Beltrametti et al., 2017). This technological evolution is exponentially increasing the possibility of being able to create systems characterized by high automation, where the human component is of fundamental importance (Celaschi, 2017).

In fact, the application of new technologies in corporate environments does not have effects on production processes only, but also on the way of working, on operators' skills and on business organization. The use of these innovations necessitates the operator developing new skills, such as the ability to be able to work in a team, to be able to solve complex problems and to adapt to working methods which are different from the standard, managing multiple machines at the same time and moving between different production workplaces:

> "these are low-hierarchy organizations, with a pronounced team spirit, with multiple skills and capable of opening themself up to new solutions and new forms of work" (Carvelli & Sapelli, 2018, p.20).

Companies are faced with a profound paradigm shift characterized by a high interconnection and cooperation between machines, production departments and workers. Operators who interact with new technological tools, learn new ways of using and controlling the machines as well as different space management. In fact, the introduction of new enabling technologies will inspire new approaches by operators towards their work tools and new organization and arrangement of lines and machines (Fantoni, 2018).

2. Collaborative robotics

The research project *"PReST: Processi, Relazioni, Spazio e Tempo: valorizzare il lavoro umano nella transizione all'Industria 4.0"*, conducted by Iuav University of Venice and Ca' Foscari University of Venice, analyzed and identified the organizational innovations capable of enhancing human work in the industry 4.0 transition in the Veneto region. In particular, the issues concerning organization of work and production processes were studied in depth, with particular interest in human-machine interaction. Part of the research focused on collaborative robotics which represents an interesting case study, as it constitutes one of the fundamental elements of Industry 4.0 in terms of flexibility, adaptability and reconfigurability of production. Collaborative robots are part of an "evolutionary" growth of machines (Magone & Mazali, 2016) that are totally transforming the relationships between machine and user with greater attention to the needs of operators.

This generates new health, productivity and safety conditions in the workplace. From the study and analysis of the current state of cobots (Vicentini, 2017) in companies and their use, reflections emerged on these products and consequently on their design methods. Cobots are automated systems for direct physical interaction (Colgate & Peshkin, 1999) capable of performing a variety of functions to assist the operator. In practice

> “this means that the cobot takes on repetitive and precision tasks as well as the heavy lifting, while a person brings the brains and dexterity to the operation. Cobots, in this way, are literally extending the workers’ physical capabilities.” (Daugherty & Wilson, 2018).

Today collaborative robotics is one of the main development processes of Industry 4.0. To develop it further, it is necessary to involve employees, since the human component represents a necessary and indispensable element for the proper functioning of the company production system. In this context, in which the man-machine relationship is increasingly important and in which a worker interacts with multiple machines, design plays a central role. A process of change is taking place and it is necessary to effectively understand the main transformations in 4.0 development processes and in particular in the process of "man-machine hybrid". (Campagna et al., 2017).

3. The operator as a central element in the design process

Collaborative robots are used to provide automation elements in manual applications with the intention of supporting the operator in order to increase his capacity, depriving him of a series of tasks more suited to machine execution. For example, when it comes to handling very flexible objects and materials with an imprecise shape, the manual abilities and competences of the worker are indispensable. On the other hand, when it comes to handling more rigid elements, the robot can be an "incomparable co-worker" (Vicentini, 2017, p.6).

So, the worker, in the production process is a figure characterized by a high level of importance, because of being equipped with considerable cognitive skills. For this reason, the worker is entrusted with tasks that bring a greater value than those performed by cobots, which are used more in the execution of high-risk operations for users.

Therefore, in order to oversee a complete and efficient design of cobots and all those machines that create an interaction with the human being, it is appropriate to avail of a user-oriented approach (Mincolelli, 2017). The focus is no longer on the automated robot, the machine or the interface, but first of all, it is the operator who must be analyzed to identify the possible ways of interaction that he can adopt in order to collaborate with the machine. Therefore, once the context of use has been defined, the design team must analyze the needs of the operators, in order to create a design proposal capable of satisfying a series of requirements to increase the simplicity and speed of use with the work tool.

4. Research methodology

The research team began an investigation, and a first draft of methodology was done in order to decide on the various research activities. Then a series of interviews took place with various stakeholders, including researchers, trade unionists and company managers, in order to identify which opinions they had regarding Industry 4.0 processes. The goal was to establish a concrete and complete definition of innovations, not only from a theoretical point of view, but effectively researching the main changes in everyday routine and those which occur in individual 4.0 operators. Companies were identified on the basis of specific criteria, in order to carry out internal investigation and observation. Before starting the fieldwork research phase, the research methods were agreed and defined, which were based on 40 interviews with employees, department heads and owners of 4 companies.

Anonymous questionnaires were delivered and non-participant observation was conducted on site in production departments, taking photos and making videos of the work environments, which were useful for qualitative data collection.

The research used a general inductive approach (Thomas, 2006) in order to present findings based on summaries of the data collected through interviews, questionnaires and observations. The analysis of the qualitative data focused on the identification of some "design challenges" that may emerge in the design of cobots to be introduced within 4.0 companies.

This methodology revealed how the operator orientates himself in the use of these new technologies and clarified whether if he favours the new interoperability with machines or not. This approach has proved to be crucial in order to analyze how the worker moves in his work environment and how he relates to new enabling technologies. It was therefore possible to define how all this can impact on the redefinition of the duties of his role and what the possible repercussions are on his psychophysical state.

5. Olmat and Telwin: two case studies compared

From the analysis done, two companies were identified with different characteristics in terms of number of employees and manufacturing technologies in use today. The two case studies are interesting to verify current changes in the way machines and workspaces are designed, specifically through analysis of the differences between traditional industrial robotics and collaborative robotics from the design point of view.

In the case of Olmat, a small metal-working company that produces foundry cores, a traditional industrial robot is used in the painting and palletizing phase. The only collaborative actions between the operator and the machine are identified in the activation and shutdown of the robot by the use of a special display. The man-machine relationship is reduced to these operations and to a remote control of the work, which is performed by an interface on the machine. The robot's working space is delimited by a well-defined area to maintain operators’ safety and consequently the man-machine relationship is very limited, given that if the operator crosses the robot's working area, the latter will automatically shut~~s~~ down for safety reasons.

Figure 1. Example of traditional industrial robot

In the case of Telwin, a medium-sized company that produces welders, cutting systems, battery chargers and starters, the production line has a quality control and painting management area where a small collaborative robot operates. The main function of this cobot is to spread the resin over the electrical components, thus making them waterproof and resistant. Interaction with these machines involves a programming officer and others who actively manage machine operation. In the company the employee, in addition to starting and shutting down the machine, performs loading and unloading of electrical components, cooperating with the cobot and actively checking to ensure the work is carried out correctly.

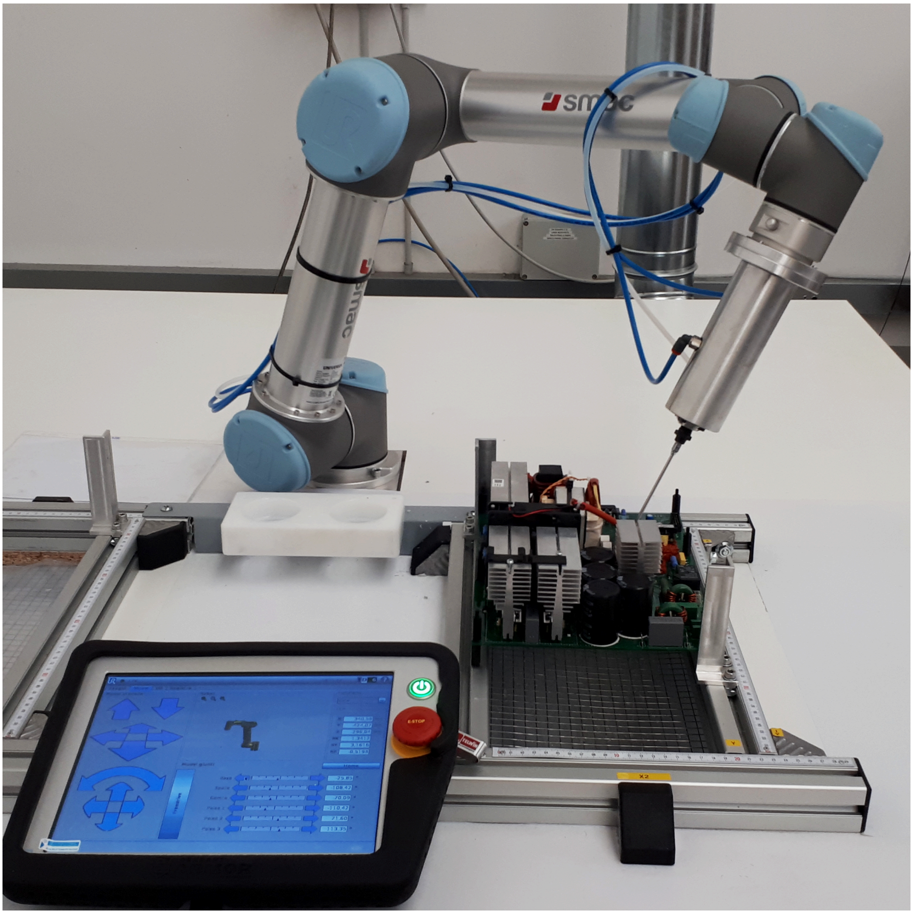

Figure 1. Example of cobot

The analysis and interviews done with employees and company managers revealed that the most efficient electronic components are produced by the combination of cobot and operators and not 100% automated. This interaction allows greater control of production and participation stimulates employees to perform better in terms of both quality and productivity. Consequently work areas take on a different layout: the cobot has no protective barriers and can interact with the user, generating an overlap of the two operating areas.

6. Design challenges: workspaces, physical appearance, human-machine interfaces

The analysis of the case studies identifies some areas of activity in which design can play a primary role, assuming three “design challenges” for the near future within companies in which the relationships between cobots and operators in the same environments will gradually become more complex: workspaces, physical appearance (Follett, 2014) and human-machine interfaces.

6.1 Workspaces

Human-machine interactions increase workers' tasks and create new methods of using the work tool. In addition, these new relationships involve a different use of workspaces, where the operator, based on the level of collaboration, can share his workspace with the area's cobot (Rhonzin et al., 2019). Specifically, collaborative solutions are designed to generate direct physical interactions with the operator within a shared space. In other words, a space in which the worker and the cobot perform specific tasks together and at the same time. For example, the worker and the cobot can perform different operations without ever meeting or making contact. But if there is a direct exchange of objects or an assisted manipulation of some components, there is a direct cooperation between the human and the automated component (Vicentini, 2017). So, in this case, the space becomes shared: the manual workstations of the operators overlap with the cobot work area, producing more common areas. In fact, in many cases the introduction of new machines involves an important change in the plant layout, especially in terms of space flexibility.

In particular, the introduction of robots in production areas generally brings the operator closer to the robotic system, producing more efficient spaces and unlimited work flows. These collaborative solutions that cooperate with the operator must be monitored and supervised for safety reasons. The cobots are equipped with sophisticated safety devices, such as displays and anti-collision systems, capable of constantly monitoring what happens in their area of operation, coordinating their movements with those of operators, thus resulting in control over their actions and forces used. During the design phase, the designer and all the players involved in the process must try to remove or limit accidental contacts that could be created between the cobot and the operator during the work operations as much as possible.

To do this, it is essential to analyze the cobot’s movements when it is operative and its position with respect to the worker in order to carry out an accurate risk analysis. Since cobots are specifically designed to work with the operator without the use of protection barriers, it is essential to program these machines in order to regulate their speed in the vicinity of an operator and to insert special locking systems that allow the cobot to be stopped at the minimum contact with the worker and to optimize the operating spaces.

6.2 Physical appearance

A further important aspect to consider for the design of these machines is represented by the construction of shells, which are not only used to protect the internal technology of the cobots but also to confer anthropomorphic shapes (Fornari, 2012).

In fact, for the design and construction of machines that must cooperate with the human being by sharing the same workstation, the design team must be able to design efficient robots, not only from a functional and safety point of view, but also by identifying forms to make operators more comfortable. This is an aspect not to be overlooked, as the intent to give robots human features is not done for simple aesthetic reasons, but to create an interaction that can be as natural as possible, to facilitate and prepare the operator from a psychological point of view into accepting the idea of having an industrial machine at his side more easily. In addition, this helps the operator to perform the tasks with more ease, lowering the level of frustration, the risk of making mistakes and also preventing accidents.

Therefore, the design of cobots and their shapes must start from an analysis of users and all their needs, in order to create design solutions that facilitate operators and their work in a variety of settings.

6.3 Human-machine interfaces

Human-machine interfaces (HMI) play a fundamental role in interacting with cobots, since they are used to make complex systems more understandable and easier to use, acting as a filter between the machine and the user (Aranburu, 2018). In fact, through the interface, the operator can communicate with the robotic system in order to perform a series of actions, including turning on, turning off, controlling and monitoring the machinery. In the design of human-machine interfaces for interaction with cobots, it is necessary to consider all the human variables of the users who approach these devices, through considerable collaboration between all the players involved in the design process: the designer, the ergonomist, the perception psychologist, the engineer. In particular, since it is an interaction process between different types of users, the first aspects that the design team must consider is usability and user experience (Pfeiffer et al., 2016). So, first of all it is essential to analyze the various needs and the cultural and technical background of the user, to establish which functions must be assigned to the machine and which ones to the operator.

In this context, the operator who uses the interface should have the possibility to take actions intuitively and quickly, through a clear and evident arrangement of symbols and messages. For example, if the user has to perform daily interface operations with the device very quickly, the arrangement and schematization of the signals and messages must be clear and effective.

From this perspective the visual arrangement of symbols and buttons should be coherent, clear and at the same time not too schematic, to avoid generating cognitive chaos, and to make the approach to the machine as intuitive and natural as possible.

7. Conclusions

The analysis carried out highlights the importance of the "dialogue" between the machine and the operator within the new paradigm of the digitized factory. The case studies demonstrate how human-machine interaction and the design of production spaces are changing in relation to the use of a traditional industrial robot or a cobot. In the near future, collaborative robots will increasingly join traditional industrial robots, allowing a higher level of cooperation with the operator. By taking advantage of direct physical interaction, the operator will be able to spontaneously and safely interact with the machine, with the possibility of bidirectional communication regulated by design.
Considering the important role of design in enhancing the relationship between humans and cobots, today it’s possible to identify at least three major “design challenges”, which can be summarized in workspaces, physical appearance and human-machine interfaces.
In the near future, these areas of studies will become fundamental to define reliable guidelines for the design and development of collaborative robots in industrial sector, in order to augment and enhance human capabilities.

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