Designing a human-centric manufacturing system from a skills-based perspective

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Abstract. This publication aims to delve into the concept of human-centric manufacturing systems (**or human-centered**) and the essential skills needed for their successful implementation and promotion. Through a combination of expert focus group and stakeholders' workshop, this research strives to develop a comprehensive understanding of the key elements that define a human-centric manufacturing (HCM) system and the crucial role played by human factors. By analyzing the outcomes of these workshops, the authors intend to uncover valuable insights regarding the skills and knowledge required for designing, developing, and implementing HCM systems. Main concepts and skills have been discovered across three main pillars: Empowerment, Inclusivity and Safety. This exploration will also encompass a deep comprehension of the role of the various functional units within an organization, emphasizing the significance of collaboration and communication amongst all stakeholders involved within a HCM context. The findings from this study make valuable contributions to the formulation of strategies aimed at facilitating the transition from an Industry 4.0 to Industry 5.0 manufacturing system and the emerging Society 5.0.

Keywords: Industry 4.0, Industry 5.0, Skills, Human-centric Manufacturing, Focus Group.

1 Introduction

Along with the technological development, new ways of conceiving the link between manufacturing context and human-centric approaches have emerged. One of these ways is the so-called "Industry 5.0" [1, 2] which emerges from the idea that Industry 4.0 places less emphasis on the fundamental principles of social fairness and sustainability, instead prioritizing digitalization and AI-powered technologies to enhance production efficiency and flexibility. With the introduction of Industry 5.0, there is a shift in perspective that underscores the significance of research and innovation in enabling the industry to serve humanity in the long run while respecting the limits of our planet. Furthermore, another paradigm has been coined, in particular it is "Society 5.0" [3] that "represents the vision of a new human-centered society, where

advanced technologies are applied in everyday life, and in different spheres of activity, to provide products and services satisfying various potential needs as well as reducing economic and social gaps, for the benefit and convenience of all citizens" not clearly focusing on the industrial aspects [2]. The core of Industry 5.0 can be defined as follows: Industry 5.0 places the wellbeing of workers at the heart of the manufacturing process (human-centric manufacturing system), making production respect the limits of our planet and the harmonious symbiotic relationship between man and machine, achieving social goals that go beyond jobs and economic growth, as well as the sustainable development goal of an uber-smart society and ecological assets, becoming a robust and resilient provider of prosperity in an industrial community of shared futures [4]. This new perspective sheds light on both how a working environment should be, and which are the paramount abilities and skills an employee should have. In order to promote a human-centric manufacturing (HCM) system vision that places fundamental human needs and interests at the center of the production process, moving away from a focus on technological advancements towards a more human-centered and society-centered approach [1] workforce needs, at least, to acquire and master those skills developed in Industry 4.0 systems [5]. Furthermore, through the introduction of Industry 5.0, businesses must pay particular attention to the well-being of their workers, on many dimensions, whose main pillars can be identified in: *safety*, *empowerment* and *inclusivity* [6]

The term Industry 5.0 was firstly introduced on December 1st, 2015, in an article published by Michael Rada on LinkedIn social network. For Michael Rada, Industry 5.0 is the "efficient use of machines and people labor in a synergistic environment" [7].

The European Commission for Innovation, Research, Culture, Education and Youth [8] points out that Industry 5.0 complements and extends Industry 4.0. It has a focus on aspects that are not only economic or technological in nature, but which will be decisive for the place of industry in European society in the future. This includes ecological, social and fundamental rights aspects. Industry 5.0 is neither the successor nor the replacement for the existing Industry 4.0 [9]. It is the result of a forward-looking exercise designed to help shape the way in which European industry can co-exist with emerging trends and needs in society.

Furthermore, it is important to ensure that workers have access to the necessary resources and support, such as mental health services, to enable them to cope with the changes brought about by the transition [8].

This work has been conducted in order to ease the shift from the current Industrial concept (I4.0) to the new one (I5.0) and to create the foundation for the education of companies and people that will deal with the future HCM system. The main objective of this paper is to explain and delineate the peculiarities of a HCM system, focusing on the skills a worker should possess and why we need such an industrial conception, creating awareness around the meaning of HCM and its three main constructs, Empowerment, Inclusivity and Safety, and identify which are the skills employees should have. It is also important to highlight the connection between a Human-centric manufacturing system and the digitalisation of Product Lifecycle Management, in particular the Digitalisation of Manufacturing System, indeed in the article [10] it has been

stressed that a virtual validation by means of a PLM software can ameliorate and improve safety processes of a manufacturing system. Therefore, the use of digital tools for building an industry environment, where Empowerment, Inclusivity and Safety are at the centre, is paramount and essential. This paper is the result of what have been done during two workshops for the European Project DE4Human, in which academic and industrial specialists have taken part. DE4Human project has been funded by EIT Raw Materials and its mission is upskilling white collars of automation manufacturing to use design thinking methodologies to redesign human centric manufacturing process towards a safer (DE4SAFETY), more inclusive (DE4INCLUSIVITY) and empowered (DE4EMPOWER) processes and workplace.

This article is divided into five sections. First, the Introduction through which a rough introduction of Industry 5.0 concept and the HCM challenges has been provided. Secondly, a theoretical background of the main pillars characterizing Industry 5.0 will be presented. Thirdly, the research methodology based on two workshops, will be thoroughly described. A fourth section will provide the information gathered by means of the two workshops. The following part will be about the discussion of results. Finally, the authors will conclude the work by providing limitations and future research directions.

2 Theoretical Background: Industry 5.0 and HCM System

Industry 5.0 is the term used to describe the latest stage of industrial evolution, characterized by a fusion of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and smart automation systems with the human workforce, with the aim of creating a collaborative environment between human and machine [11]. Industry 5.0 can be seen as the answer to the demand for a new HCM system, starting from the reorganisation of production processes (in terms of structure, organisation, management, knowledge, philosophy and culture), in order to have a positive impact on the business perspective and on all the components of the innovation system [12].

This new phase of industrial development is characterized by smart, connected factories that are highly efficient, flexible, and capable of self-optimization, which is poised to foster and focus on human's creativity. Industry 5.0 also involves a deep integration of digital technologies with physical production processes, enabling real-time data collection and analysis, autonomous decision-making, and highly personalized and adaptive manufacturing [8]. This leads to increased efficiency, reduced waste, and improved quality control. Overall, Industry 5.0 represents a major shift in the way goods are produced, with a focus on creating a more sustainable, efficient, and agile manufacturing process. Furthermore, in a recent Financial Times article [13] it emerges that many industries are already in the process of embracing digitalization and AI, resulting in the automation of certain technical skills. Consequently, employers are now prioritizing human-centric abilities like problem-solving, creativity, critical thinking, cognitive agility, and empathy, so it is important to develop a set of skills which positively impact on a HCM system.

With the introduction of Industry 5.0, some concepts strictly related to the well-being of the workers have emerged, such as Safety, Empowerment and Inclusivity within a manufacturing system. Indeed, there is a strong correlation between Industry 5.0 in terms of safety. The integration of advanced technologies in Industry 5.0 has the potential to make manufacturing processes safer for workers. For example, the use of robots and automation can help to reduce human exposure to hazardous working conditions, such as in tasks that involve handling dangerous materials or working in confined spaces [14–16]. Moreover, the use of data and analytics in Industry 5.0 can help to identify potential safety hazards and prevent accidents before they occur. For example, sensors and other monitoring devices can be used to monitor the health and safety of workers in real-time, and predictive analytics can be used to identify potential safety issues and develop preventive measures. In summary, as the advanced technologies integrated in Industry 5.0 can enhance worker safety, and the focus on human well-being in human-centric manufacturing can help to ensure that workers are protected from harm in the workplace [14, 17–19].

Industry 5.0 has also a strong connection with the empowerment of workers; indeed, it has been conceived as a human-centric system in which the employees' talents are nurtured and fostered by means of "combining human beings' creativity and craftsmanship with the speed, productivity and consistency of robots" [20]. Another perspective on empowerment comes from [21] in which Industry 5.0 "emphasizes on empowering the human being specially the customers through fulfilling their personalizing and customized needs". One of the central objectives of Industry 5.0 is to reshape industrial employment in terms of improving the wellbeing and empowering workers via assistive technologies [4, 22]. As a path to the digitalised production of the future, this integration of human workers should be built on the achievement of the I4.0 technology-driven orientation [11, 21] approaches for a flexible and human-centered integration and support of employees in the digitalized and interconnected production of the future.

Even though there is paucity of literature, another important aspect is the connection between the concept of Industry 5.0 and inclusivity (both from a company and worker perspectives). The development of worker-inclusive decision-making tools and human-centric and flexible work planning models is beginning to emerge in recent academic literature. Some emphasize that in order to develop more work-inclusive solutions, workers need to be involved in both the individual data collection phase and the decision-making phase [23–26] and others say that there is the need to train and instruct workers through an ad-hoc mentoring and tutoring approach [27] in order to make the employees more included in the manufacturing process loop.

This work refers to safety, inclusivity and empowering as the three pillars of HCM, as core system to put in place to accomplish the Industry 5.0 goals.

3 Research Objectives and Methodology

The current work purses two main objectives: i) to obtain a user-centric view of what comprises a HCM system, and ii) to obtain a skills-oriented view of the requirements

for the facilitation and realization of a HCM system. In order to achieve this purpose, two consecutive workshops were held wherein participants were asked to assume the role of designers of a HCM system. The choice of methodology arises from two key notions presented in the previous sections: the human-centricity that guides the Industry 5.0 paradigm as well as the importance of cooperation between academia and industry to address the emerging challenges. These are respectively embedded into the workshops by the adoption of user-centered design (UCD) and collaborative design (CD) as approaches during their design and execution phases. UCD is an iterative design approach based on the active involvement of users, focusing on their needs throughout the design process [28]. CD, on the other hand, brings together actors from different disciplines to share their knowledge about the design process as well as the artifact being designed [29]. Table 1 summarizes the main information related to the two workshops, in particular in the first workshop has been used an expert focus group approach while in the latter a stakeholder workshop approach, including the objective of each activity as well as the participants involved. The following sections cover in detail the design and execution of both workshops.

Table 1. Characteristics of the two workshops

Workshop	**1. Expert Focus Group**	**2. Stakeholder Workshop**
Objective	Define the three main pillars that comprise HCM and to discuss the skills that facilitate their realization	Identify the main functional units within an organization involved in the implementation of a HCM system and to discuss the skills that facilitate its realization from an organizational perspective
Participants		
Manager/PM	4	8
Professor/Lecturer	4	5
PhD Candidate	2	3
Company Employee	1	2
Consultant	1	1
Executive Director/ Director	0	5
Total	12	24

3.1 Workshop No. 1 – Expert Focus Group

The expert focus group approach has been adopted for the first workshop [30, 31]. The in-presence workshop was scheduled during 1.5 hours and brought together 12 experts from industry and academia who worked together to discuss the concept of HCM. After a brief introduction about Industry 5.0 and HCM, participants were presented with a series of prompt questions and were asked to use post-its to give their answers (see Fig. 1). The objective was to zoom-in on the characteristics of a HCM

system, focusing on the skills that facilitate the realization of its three main pillars: safety, inclusivity, and empowerment. The prompt questions were as follows:

- What is a HCM system?
- What is the meaning of *safety* within a HCM?
- What are the skills related to safety that can support the realization of a HCM?
- What is the meaning of *inclusivity* within a HCM?
- What are the skills related to inclusivity that can support the realization of a HCM?
- What is the meaning of *empowerment* within a HCM?
- What are the skills related to empowerment that can support the realization of a HCM?

Fig. 1. First Workshop

3.2 Workshop No. 2 – Stakeholder Workshop

The second workshop had a duration of 2 hours and was held remotely making use of the collaborative tool MURAL, counting with the participation of 24 individuals working in industry and academia [32]. The participants were presented with a series of prompt questions and were asked to use post-it in MURAL to give their answers (see Fig. 2.). The objective was to identify the main functional roles and units within an organization involved in the implementation of a HCM system and to discuss the skills that facilitate its realization from an organization-al perspective. The prompt questions were as follows:

- What are the roles / job positions / functions / units a manufacturing company should pay attention for implementing a HCM system?
- What are the competences / skills that can support a HCM system in an existing company?
- How such competences / skills should be transferred to those actors in an existing

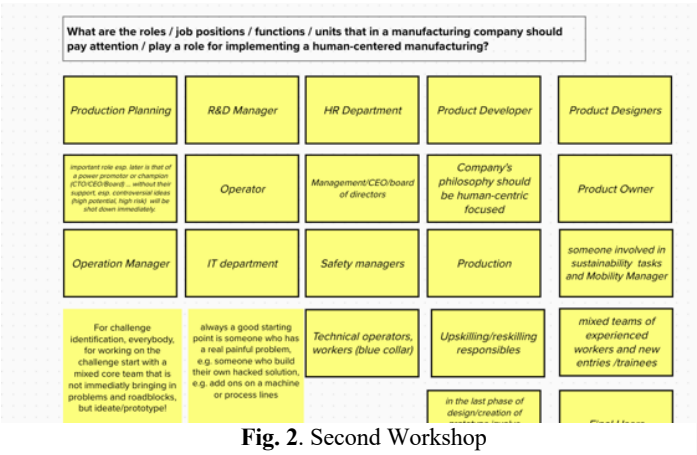

Fig. 2. Second Workshop

company?

4 Results and Discussion

4.1 Workshop No. 1 – Expert Focus Group

As a result of the first workshop, the concept of HCM was explored in detail taking as a basis the three main pillars of safety, inclusivity, and empowerment.

Safety. The participants' responses related to safety within the larger context of a HCM indicated an understanding of the concept in three different dimensions: *emotional*, *professional*, and *physical*.

- *Emotional Safety*. Refers to whether employees feel valued and see themselves as belonging to a team. This feeling of "safety" may emerge from being treated with respect and as a valuable component of the system and as more than just an employee.
- *Professional Safety*. Related to the perception of a person's job as the source of their livelihood and the means to provide for their families. This feeling of "safety" may emerge from perceiving that one's job position is not at risk; otherwise, this sense of imminent threat may undermine an employee's performance and force them to take unnecessary risks to protect their employment.
- *Physical Safety*. Makes reference to comfort in relation to the activities conducted as part one's job. This feeling of "safety" may emerge from working in an environment with furnishings that enable comfortable body posture, keeping an adequate temperature and access to all required tools to perform one's tasks.

Inclusivity. The participants' responses related to safety within the larger context of a HCM indicated an understanding of the concept in two different dimensions: personal inclusivity and work-related inclusivity.

- *Personal Inclusivity*. Refers to being accepting of personal characteristics that are inherent and do not affect a person's performance in their job. These characteristics may include age, gender, religion, ethnicity, disability, economic status, among others.
- *Work-Related Inclusivity*. Related to the different levels of skills and competences across employees within an organization. This understanding of inclusivity is of particular relevance in instances where existing employees are given larger roles within the organization or new employees enter the organization and may be perceived as unprepared.

Empowerment. The participants' responses related to safety within the larger context of a HCM indicated an understanding of the concept in two different dimensions: individual empowerment and structural empowerment.

- *Individual Empowerment*. Refers to a feeling of confidence over one's capabilities, actions, and decisions. This feeling of "empowerment" may emerge from perceiving the impact of one's actions within their organization.
- *Structural Empowerment*. Refers to the strategies and practices that are put in place and shape a workplace with the objective of facilitating individual empowerment. Therefore, structural empowerment refers to initiatives and practices that foster the sharing of power, decision-making, and control over resources.

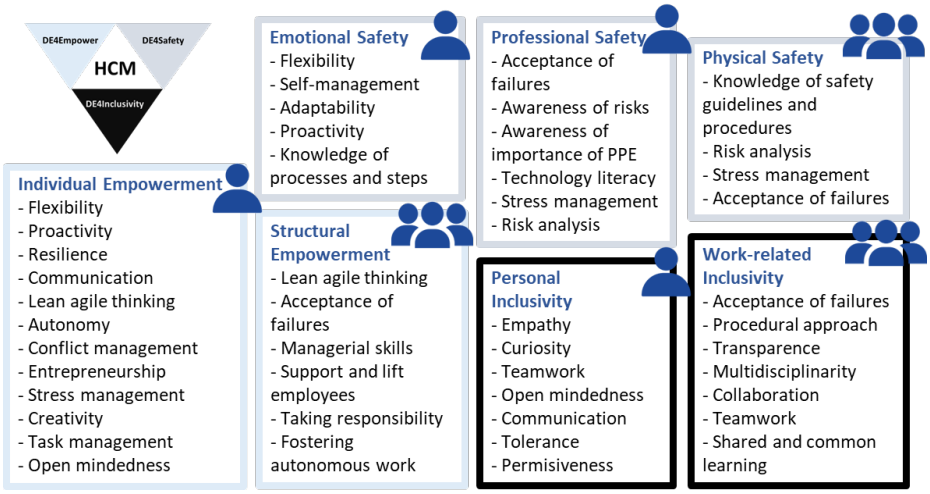

Fig. 3. Dissection of the three concepts. In particular, two skills levels have been identified: Personal Skills (one person icon), Organizational Skills (three people icon)

The dissection of these three concepts together with the skills relevant to their realization as identified by the participants (see Fig. 3.) allowed for the further identification of two skill levels across all three pillars: personal skills and organizational skills.

- *Personal Skills* refer to the way in which a person interacts with other people and the surrounding environment. Examples of personal skills include autonomy, resilience, proactivity, etc.
- *Organizational Skills* refer to the achievement of an organization's objectives in relation to the performance of one's duties. Examples of organizational skills include multidisciplinarity, delegation, time management, etc.

4.2 Workshop No. 2 – Stakeholder Workshop

The second workshop adopted an organizational perspective to identify relevant skills for the realization of a HCM system. The participants' answers showed that these skills are relevant and required not only at the factory or at the shop floor level, but

throughout the organization in different forms -i.e. different skills- and at different levels. The effective realization and implementation of a HCM system requires the involvement of the entire organization, especially during its design phase. As a result of participants' answers to the prompt questions, it was possible to identify three different types of skills from an organizational perspective: *Technical Skills, Transversal Soft Skills, Managerial Skills* (see Table 2).

- *Technical Skills*. Hard skills that are specific to a functional unit. Examples of hard technical skills include rapid prototyping in the R&D department and technology literacy in the Production department.
- *Transversal Soft Skills.* Soft skills that are relevant to the entire organization. Examples of transversal soft skills include creativity, communication, and resilience.
- *Managerial Skills*. Soft and hard skills that are relevant across management. Examples of managerial skills include leadership, change management, and networking.

Table 2. Organizational Skills Levels

Technical Skills	**Transversal Soft Skills**	**Managerial Skills**
Product/Process Design (**R&D**)	Creativity	Holistic thinking
Design for automated assembly (**R&D**)	Collaboration	Leadership
Design for X (**R&D**)	Critical Thinking	Change Management
Design Thinking (**R&D**)	Empathy	Task Decomposition
Rapid Prototyping (**R&D**)	Fairness	Networking
Knowledge about regulations related to hazardous materials (**R&D and Safety**)	Respectfulness	Abilities to overcome criticalities and problems
Technology Literacy (**Production & Supply Chain**)	Research Skills	Awareness about resources consumption
Lean Thinking (**Production & Supply Chain**)	Abilities to innovate and be intuitive	Optimization skill
	Collaborative Environment	Life Cycle Thinking
	Communication	
	Resilience	

5 Conclusion, Limitations and Future Research

Along with the technological development, new ways of conceiving the industrial manufacturing context development have emerged. One of these concepts is the so-called Industry 5.0 [2]. The core of Industry 5.0 can be defined as follows: Industry 5.0 places the wellbeing of workers at the heart of the manufacturing process (human-centric manufacturing system), making production respect the limits of our planet and the harmonious symbiotic relationship between man and machine, achieving social goals that go beyond jobs and economic growth, as well as the sustainable develop-

ment goal of an uber-smart society and ecological assets, becoming a robust and resilient provider of prosperity in an industrial community of shared futures [4].

Thanks to the two workshops the authors have been able to delineate the main concepts of HCM system and the three main pillars linked to it: *Inclusivity*, *Empowerment* and *Safety.* The main skills that should be developed within a HCM system have been listed and grouped in three main categories: *Technical Skills*, *Transversal Soft Skills* and *Managerial Skills*. Furthermore, as a workshop result, the authors have discovered "Hard Skills" that are specific to a functional unit and paramount for the development of a HCM system (see Table 2).

From the research some limitations have emerged. One of the limitations could be industry related, in particular the skills discovered could be limited to a specific sector and therefore some skills could not fit well a company's working environment. In order to overcome this limitation, interviews with operators could be conducted. Another limitation is related to the conception of the three main pillars, indeed different pillars could be discovered in the literature for other sectors and manufacturing systems based on social and less tangible characteristics.

For future studies, researchers should validate e include practical examples, for instance if industry is considering, what have been developed by this project, a core aspect within their working environment. Furthermore, an important focus should be put on the education, in fact DE4Human project sheds light on the education side and how it could ameliorate the transition towards a safety, inclusive and empowered Industry 5.0 manufacturing system.

To conclude, research should also be carried out on the correct use of the concepts, because sometimes some paradigms have overlaps (e.g., Industry 5.0, Society 5.0 and Working World 4.0).

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