Building the Workforce of Tomorrow: A Systematic Literature Review of the Essential Skills for the Future Industrial Landscape

Luca Carminati*, Roberto Sala*, Fabiana Pirola*, Virginia Capriotti, Francesco Magni**, Mohammad Hossein Dehbozorgi***, Monica Rossi***, Sergio Terzi***, Rossella Pozzi****, Tommaso Rossi******

** Università degli studi di Bergamo, Dipartimento di Ingegneria Gestionale dell'Informazione e della Produzione, University of Bergamo, Viale Marconi, 5 20044 – Dalmine (BG) – Italy (luca.carminati@unibg.it, roberto.sala@unibg.it, fabiana.pirola@unibg.it)*

*** Università degli studi di Bergamo, Dipartimento di Scienze Umane e Sociali, University of Bergamo, Piazzale S. Agostino, 2 24129 – Bergamo (BG) – Italy (virginia.capriotti@unibg.it, francesco.magni@unibg.it)*

**** Politecnico di Milano, Dipartimento di Ingegneria Gestionale, Polytechnic University of Milan, Via Raffaele Lambruschini, 4/B 20156 - Milano (MI) – Italy (mohammadhossein.dehbozorgi@mail.polimi.it, monica.rossi@polimi.it, sergio.terzi@polimi.it)*

***** LIUC Università Carlo Cattaneo, Dipartimento di Ingegneria Gestionale dell'Informazione e della Produzione, LIUC University Carlo Cattaneo, Corso G. Matteotti, 20 21053 - Castellanza (VA) – Italy (trossi@liuc.it, rpozzi@liuc.it)*

Abstract: The fourth and fifth industrial revolutions have significantly transformed manufacturing, introducing new perspectives and foundational beliefs, particularly in promoting sustainable manufacturing practices. This shift requires rethinking the competences and decision-making processes that workers must have to work in the new environment. To help students in being competitive on the job market, educational institutions must align their educational programs to address the new requirements. Thus, this research aims to identify the skills that future workers must have to be appealing for companies that want to operate in an environmentally conscious and socially responsible industrial landscape. To do so, a systematic review of existing literature was carried out. To offer a complete overview of the evolution of the competencies and identify important trends, the study tracked the frequency of citations for skills over time. These skills can be taught through learning factories, which can be used to provide students with practical applications of theoretical knowledge, ensuring that learned competencies are not only theoretical but also practical and applicable in real-world scenarios. This research offers valuable insights into the evolving debate on skills, which can be useful for the development of educational programs, learning activities and targeted training initiatives for workers.

Keywords: Skills, Sustainable manufacturing, Industry 5.0, Learning factories

1. Introduction

In recent years, the evolution of Industry 4.0 technologies has raised the debate on how to fully exploit their potential, not only from an efficiency point of view, but also to promote social and environmental sustainability. This has led to the emergence of the concept of Industry 5.0 (I5.0), which aims to make production environmentally and socially sustainable while also prioritising the wellbeing of workers (European Commission. Directorate General for Research and Innovation., 2020). The objective of I5.0 is translated into three main components – resilience, sustainability, and human-centricity – that should be embraced by organisations to be competitive in the current industrial context. This involves the adoption of new technologies that should take into consideration human factors by assessing the impact of technologies on work activities and quality of work (e.g. the consequences of introducing artificial intelligence and automation tools) in order to achieve more sustainable manufacturing processes (Friedman & Hendry, 2019).

It is important to note that possessing the knowledge of something is not enough to promote economic, social and environmental sustainability; skills are needed. The concept of "skill" is related to the competent acquisition and use of something (Bertagna & Triani, 2013). Therefore, knowledge must be transformed into practical skills. Innovative teaching methods that offer practical application of acquired knowledge should be investigated and researched as they contribute to the development of necessary skills (Azer et al., 2013). Among them, teaching methods leveraging on teaching and learning factories can be beneficial as they are environments where students can experiment, solve problems, and assess opportunities, leading to the development of skills (Lagorio & Cimini, 2024).

Current and future workforce should be provided with the necessary skills to tackle new environmental and social challenges and maintain the efficiency of business activities (Borchardt et al., 2022). Technical skills, despite being necessary, are not sufficient. Therefore, investing time in developing non-technical skills is also essential (Suciu et al., 2023).

The aim of our study is to investigate the skills required for future workers to operate in the context of I5.0, with a specific focus on sustainability and human-centricity, through a systematic literature review (SLR). Once identified, skills were analysed and categorized into technical, methodological, personal, and social to determine the most discussed and how research on them has evolved over the years.
In section 2, the methodology used is presented along the main results (Section 3). Section 4 provides a discussion of the findings while Section 5 briefly concludes the study delineating future research.

2. Methodology

The PRISMA methodology (Selcuk, 2019) was adopted to conduct the SLR. In February 2024, a query was entered into the Scopus database to meet the research objective. The query was structured around the themes of A) Industry 5.0, B) the connection between Industry 4.0 and sustainability and human-centricity and, C) the necessary skills and competencies for working in the new industrial context. Table 1 details the keywords used for each theme.

Table 1: Keywords for research query.

I5.0 (A)	I4.0 and sustainability and human-centricity (B)	Skills and competencies necessary (C)
“Industr* 5.0";"I5.0";"Servi* 5.0";"manufactur* 5.0";"technolog* 5.0";"Operator* 5.0"	"Industr* 4.0";"I4.0";"manufactur* 4.0";"technolog* 4.0";"Operator* 4.0";Sustainab*;"Human cent*";"Human-Cent*"	*skill*;competenc*;abilit*;knowledg*;capabilit*

While “resilience” is considered as one of the main pillars of I5.0, it has been excluded from the research query as our focus is mainly on sustainability and human-centricity. The analysis of skills necessary for the future of manufacturing has been prioritised, with a particular emphasis on the environmental and social dimensions. The query has been designed to connect themes and keywords to retrieve documents relevant to our research questions. The query used was: ((TITLE-ABS-KEY ("Industr* 5.0" OR "I5.0" OR "manufactur* 5.0" OR "technolog* 5.0" OR "Operator* 5.0") OR (TITLE-ABS-KEY ("Industr* 4.0" OR "I4.0" OR "manufactur* 4.0" OR "technolog* 4.0" OR "Operator* 4.0") AND TITLE-ABS-KEY (sustainab* OR "Human cent*" OR "Human-Cent*"))) AND TITLE-ABS-KEY (*skill* OR competenc* OR abilit* OR knowledg* OR capabilit*)). The following filters have been implemented to improve the accuracy of the query: Timespan ranging from 2018 to 2024, Publication stage set to Final, Type set to Article or Conference Paper, Language set to English, Subject Area encompassing Engineering, Computer Science, Business Management and Accounting, Social Sciences, Environmental Science, Decision Sciences, and Multidisciplinary.
The relevant documents for our analysis were extracted according to the PRIMA methodology. As described in Figure 1, the search resulted in an initial pool of 1657.

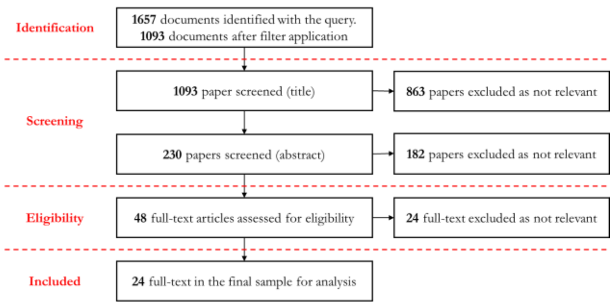

Figure 1: PRISMA flow diagram of the SLR.

A significant number of papers were found to be irrelevant as they did not meet the inclusion criteria, which required clear definitions of the necessary skills and their relevance to sustainability and a human-centric approach. Documents that did not discuss the specific skills required for Industry 5.0 or sustainable manufacturing were excluded from the analysis. 24 relevant papers were identified and used to answer the research question.
Skills were extracted from the papers and duplicates were removed. Following, skills with different names but the same meaning have been merged, such as “knowledge dissemination” and “knowledge and experience sharing”. The skills that successfully passed this process were then categorised into personal, technical, methodological and social, according to the methodology presented by Hecklau et al. (2016) (Table 2).

Table 2: Definition of Skill Categories.

Typology	Description
Technical (T)	Refers to the specific knowledge and skills needed to efficiently and effectively complete tasks in a particular job role, directly related to its technical aspects.
Methodological (M)	Refers to the abilities and approaches individuals utilize to complete tasks and solve problems in a structured and efficient way.
Personal (P)	Refers to the abilities that influence how an individual approaches challenges, learns, and achieves goals.
Social (S)	Encompasses the abilities individuals utilize to interact effectively with others, build relationships, and foster collaboration.

3. Results

As previously mentioned, the final sample comprises 24 articles. Figure 2 illustrates a growing yearly publication of papers, denoting an increasing interest in the topic. 2024 presents only two papers due to the moment of execution of the query.

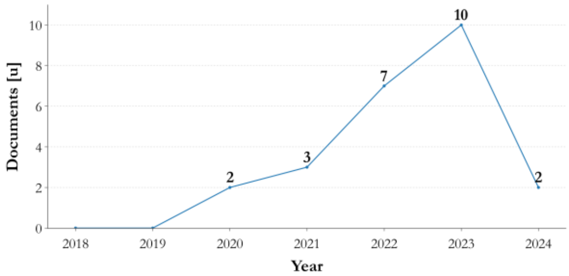

Figure 2: Documents publication trend (final sample).

A total of 356 skills were extracted. After removing duplicates, 232 skills remained. Following the merging of skills with the same meaning but different descriptions, 106 relevant skills were selected. After categorisation, 17 personal competences, 45 technical competences, 30 methodological competences and 14 social competences were identified. Tables 3 to 6 report the top five (per total citations) skills per category, as emerging from the analysis. For space reasons, each reference has been associated with a code. You can find the legend for these codes at this link.

3.1 Technical skills

Table 3 shows the most cited skills for the technical area.

Table 3: Top 5 Technical skills out of 45 identified.

Technical Skill (T)	Reference	Cit.
Data Management	1,2,3,4,5,6,7,8,9,10	10
Artificial Intelligence	1,3,5,11,12,7,13,14,10	9
Internet of Things	2,3,12,7,8,13,14,15	8
Development and implementation of robotic systems	2,3,7,12,8,14,10	7
Cybersecurity	3,6,7,14,16,17	6

Data management is the most frequently mentioned skill required for sustainable manufacturing. The increasing use of digitalisation within companies requires the ability to deal with large amounts of data, to make effective decision and manage new technologies (Kowal et al., 2022). Data visualization, data science, data mining, and data analysis are all considered essential skills for the future workforce (Aranda et al., 2023). It is not enough to simply collect and analyse data; companies also require individuals capable of interpreting this information (Chari et al., 2022). Additionally, effectively managing the security of sensitive data is crucial (Kowal et al., 2022). Therefore, cybersecurity and artificial intelligence skills are both relevant. Tools, such as Chatbots (e.g., ChatGPT) and Robotic Process Automation (RPA), can assist workers in providing necessary information, answering questions, and supporting their work activities, ultimately adding value to core business processes (Aranda et al., 2023). Another important technical skill is related to the use and management of the Internet of Things (IoT). Interconnecting different technologies is essential to achieve strategic and efficiency objectives. For instance, the ability to use IoT technologies can optimize waste collection and recycling processes, enabling the company to achieve its sustainability goals (Nobre & Tavares, 2023). Other relevant technical skills for operating in the context of sustainable manufacturing and Industry 5.0, which can be extracted from the references in Table 3, are: skills in effectively using and designing online platforms (e-commerce), digital content creation (design), machine learning, Augmented Reality (AR), process optimization, cloud solutions, circular business models, IT management, Information and Communication Technologies (ICT), Virtual Reality (VR), Cyber-Physical Systems (CPS), software development, eco-friendly products, automation, preventive and predictive maintenance, sustainable resource management, renewable energy, digital twin technology, 5G networks and quality management.

3.2 Methodological skills

As reported in Table 4, life-long learning and problem-solving skills are among the most fundamental ones for future workers. These skills are essential for assimilating the knowledge needed to ensure coordination between different components and to innovate in new environments (Kowal et al., 2022; Kruger & Steyn, 2021).

Table 4: Top 5 Methodological skills out of 30 identified.

Methodological Skill (M)	Reference	Cit.
Lifelong learning	18,3,19,5,6,20,16,17,9,10,21,15	12
Problem-solving	2,3,22,20,16,17,23,10,15	9
Decision making	1,2,3,16,17,21	6
Critical thinking	3,19,11,24,10	5
Entrepreneurial skills	2,3,11,16,17	5

This continuous update of knowledges is also fundamental to achieve and meet the sustainable goals that have arisen in recent years (Da Silva et al., 2022). It is also important to develop problem-solving and decision-making skills. These skills must be acquired and strengthened by workers who intend to work in the industrial context of the future. The deep connection between technology and humans in companies demands, in fact, the ability to find and adopt specific solutions to problems arising from this integration (Shet & Pereira, 2021). Critical thinking is also considered essential, as it is important to understand and interpret the information provided and gathered by technology (Leon, 2023). Additionally, entrepreneurial skills, such as defining goals and motivating teams, help to recruit people with the right attitude and skills for the company (Shet & Pereira, 2021). Skills related to information analysis, research formulation, decision-making, user-centric design methodologies, sustainability integration approaches, workplace safety management, organizational coordination techniques, resource allocation methods, project planning strategies, business model innovation processes, product lifecycle oversight, risk management methodologies are also considered important by the references mentioned in Table 4, although these skills are mentioned less often than those previously discussed.

3.3 Personal skills

Table 5 shows the most cited skills for the personal area.

Table 5: Top 5 Personal skills out of 17 identified.

Personal Skill (P)	Reference	Cit.
Creative and innovation thinking	18,25,11,12,6,8,24,23,10,17,15,4	12
Leadership	2,3,11,16,17,23,21,15	8
Adaptability to change	18,3,4,22,10,21	6
Flexibility	2,14,16,17,21	5
Emotional intelligence	11,20,23,21	4

Personal skills are highly valued in the new industrial context as they are difficult to automate. Also, personal skills require special attention since they are difficult to develop through training or teaching (Kowal et al., 2022). Creative and innovative thinking is particularly important for updating business models in response to changes in the external environment, as well as for designing new products and services and identifying opportunities in new business areas (Kruger & Steyn, 2021). It is important to be creative not only in the design of new products, services and technologies but also in understanding new environments and trends, such as sustainability and digitalization, and how to fit effectively into them (Taverner et al., 2021). Leadership is crucial not only for guiding teams towards the company's objectives but also for identifying and hiring the right talent. An engineer with leadership skills should also be able to assess opportunities using innovative ideas (Shet & Pereira, 2021). The ability to change plans, routines and procedures quickly is seen as necessary for working in sustainable manufacturing, as the industrial context is rapidly evolving and implies important changes in working practices and processes. Emotional intelligence is a necessary skill for promoting a positive workplace environment and also for comprehending workers' emotions and retaining talent (Kulkarni & Patil, 2024). Other relevant personal skills for the new working context, which can be extracted from the references in Table 5, include ability to motivate and commit to environmental improvement, ability to cooperate, empathize with others, perform effectively in high-pressure environments, demonstrate perseverance, make ethical decisions and actions, identify and address problems and opportunities.

3.4 Social skills

Table 6 shows the most cited skills for the social area. Social skills are considered fundamental to work in the new interdisciplinary and human-centric industrial context (Kowal et al., 2022). This is because the new working environment requires collaboration, teamworking, and communication skills, both in physical and virtual settings. Additionally, training skills are also essential to face new challenges. Training should be continuous and effective, focusing on the necessary skills and the best methods for teaching them to new workers. The training should be tailored to the specific trainee (Aranda et al., 2023).

Table 6: Top 5 Social skills out of 14 identified.

Social Skill (S)	Reference	Cit.
Communication skills	18,25,3,19,11,6,22,24,20,16,17,23,10,15	14
Teamworking	25,3,11,6,16,17,10	7
Intercultural skills	3,6,22,16,17,10	6
Collaboration	2,4,24,10,21,17	6
Training skills	4,7,21	3

Among social skills considered relevant by the references mentioned in Table 6, it is worth also mentioning the ability to access external expertise and know-how, the ability to lead, motivate, and supervise teams for enhanced productivity and collaborative success and the commitment and abilities to pay attention to human rights, foster employee well-being, and promote inclusiveness within organizational practices.

4. Discussion

The systematic literature review identified 106 skills required for work in a more sustainable manufacturing context. The analysis of these extracted skills was conducted based on their occurrence by year. It is important to note that no relevant skills related to the research topics were identified in 2018 and 2019. This is likely due to the research query's focus on Industry 5.0 and its associated themes, such as sustainability and human-centricity. These themes became prominent in 2020 due to the European Commission's decisive role in defining Industry 5.0 (European Commission. Directorate General for Research and Innovation., 2020). Figure 3 shows the year a skill was mentioned and its reference category. Skills in lighter colours were mentioned in previous years, while darker-coloured ones were introduced as new skills in a particular year. For example, if leadership was referenced in 2021, it will appear in a lighter colour in 2022, indicating a previous mention. However, if it was not mentioned until 2022, it will appear in a darker colour, signifying its introduction as a new skill. Figure 3 indicates that new skills were added to the necessary pool for sustainable manufacturing in 2020, 2021, and 2022. In contrast, 2023 and 2024 mainly confirmed skills previously identified, even though only a few months of 2024 were analysed.

Despite being closely linked to Industry 4.0 topics, technical skills remain crucial. To take full advantage of available technologies, mastering them is vital while aligning with the economic, environmental, and social requirements of sustainable manufacturing (Krajčo et al., 2019).

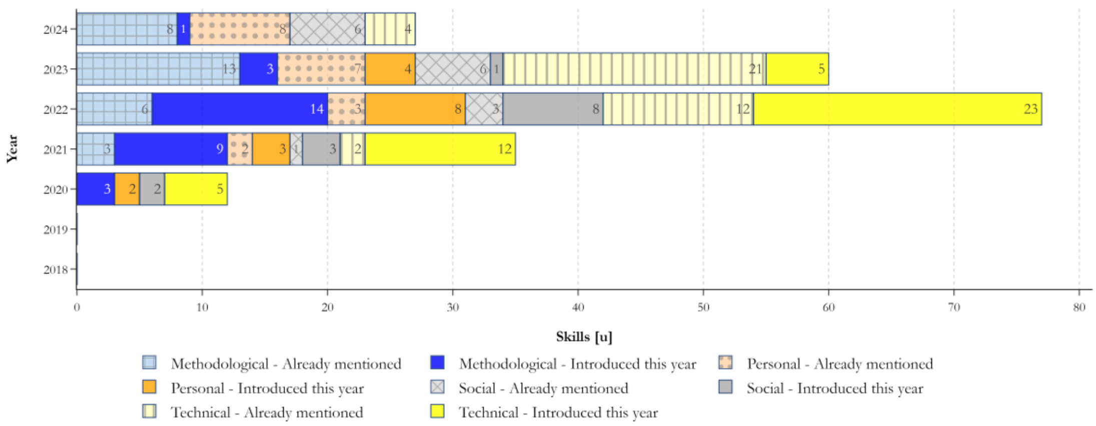

Figure 3. Skills over time.

Personal, social, and methodological skills constitute over half of the skills mentioned each year during the study period. The proportion of skills identified in each category stayed consistent, suggesting no single category dominated. However, the importance of transversal skills is expected to rise in the future (García-Álvarez et al., 2022). Hence, understanding how to effectively teach these skills to students and future workers is critical. Moreover, there has been a growing trend in the number of skills mentioned annually, which is anticipated to persist in 2024 due to increased interest in sustainable manufacturing.

A Python script and the library pyVis were used to analyse the relationships between different skills mentioned in the literature. In Figure 4, a relationship is represented by an arc connecting two nodes (skills), indicating joint mention in the same paper. The arc's thickness signifies the relationship's strength, reflecting how many times the skill pair was cited together in the literature. A larger node denotes a skill frequently cited in the literature. The graph, like the analysis of citations per year, covers the period from 2020 to 2024. Due to the vast data volume, a weight of ≥ 3 of the arcs was implemented for representation clarity. This means only skill pairs mentioned together at least three times in the literature were included. The nodes are color-coded based on skill category: black for social skills, blue for methodological skills, orange for personal skills, and yellow for technical skills. The colour of the arcs will match that of the nodes if they belong to the same skills category; otherwise, it is red. As it is possible to notice in Figure 4, the most central skills are primarily related to personal, social, and methodological categories, such as creative thinking, communication skills, problem-solving, leadership, teamwork, and lifelong learning. An analysis of the five strongest relationships reveals that communication skills feature in four out of five, along with lifelong learning, creative thinking, problem solving, and teamwork. This underscores the importance of soft skills in the contemporary industrial context. While technical skills may be task-specific, soft skills are essential and applicable across all roles, facilitating efficient work processes (Marin-Zapata et al., 2022). Consequently, there is a need to initiate programs focused on developing soft skills early in an academic career. To cultivate these skills, additional teaching methods like frequent group activities, projects, simulations, and serious games should be utilized, alongside dedicated soft skills courses (Caeiro-Rodriguez et al., 2021). Figure 4 illustrates the strong link between lifelong learning and problem-solving skills. Problem-solving abilities must be paired with continuous learning to keep up with trends, global events, and knowledge required for new industrial contexts, enabling future workers to tackle potential challenges (Gürdür Broo et al., 2022). Figure 4 reveals also that the most relationships between skills, within the constraints applied to the arcs, are cross-category (red arcs), as opposed to within-category. However, there are also relationships within the methodological category, most notably between lifelong learning and problem solving, and within the technical skills category, which has many relationships conforming to the imposed weight constraint. In line with Industry 4.0 themes, these relationships are frequently cited in literature.

Robotics and Artificial Intelligence have the strongest links to the Internet of Things in the technical category. Industrial robotics and artificial intelligence tools need to be integrated with all other digital and technological systems in a company to maximize potential (Aoun et al., 2021). This also allows for extensive data collection, which must be accurately analysed and interpreted to add value to the company. So, the relevance of the relationship between data management and robotics in the technical skills category underscores the importance of data management and analysis skills in enhancing the efficiency of industrial robotics (Javaid et al., 2021). Notably, the technical skills with stronger relationships to other transversal skills categories are data management, cybersecurity, and artificial intelligence. This reiterates the importance of skills such as creative and critical thinking, leadership, problem-solving, and lifelong learning in fully leveraging new technologies. It also underscores that technical training should be integrated with training in more transversal skills, recognising their equal importance in a well-rounded education (Lamri & Lubart, 2023). All these identified skills must be developed in students. Providing students with opportunities and safe spaces to test their learning is crucial. Teaching and learning factories could facilitate competence development, allowing students to apply the knowledge gained in university courses (Lagorio & Cimini, 2024). This hands-on approach to learning not only helps in developing necessary skills but also stimulates creative thinking.

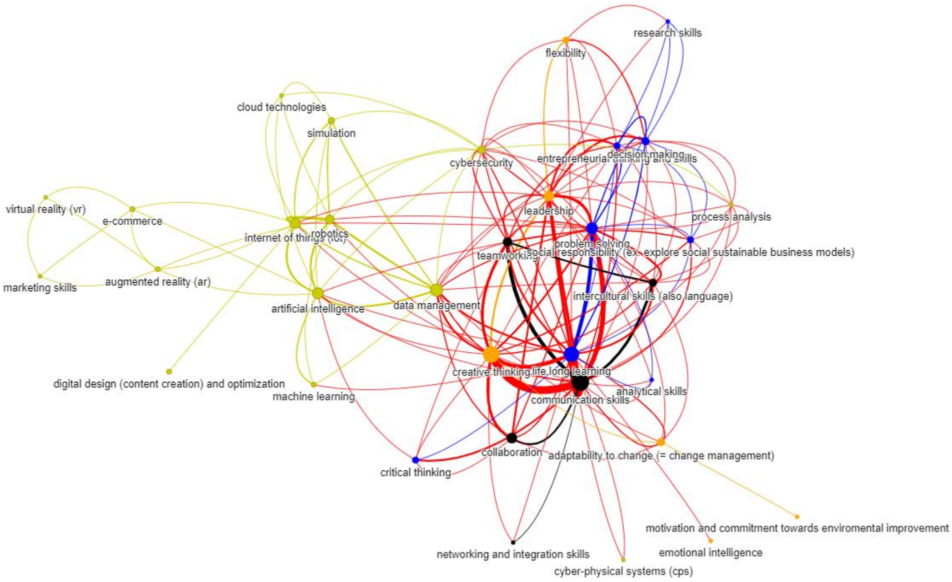

Figure 4: Network analysis of the skills.

By encouraging students to think creatively, it prepares them to handle future challenges and seize opportunities. This approach also fosters a culture of innovation and problem-solving among students. Thus, the effective use of teaching and learning factories in education can have a profound impact on the development of a student's technical and transversal skills, better preparing them for their future challenges.

5. Conclusion

In conclusion, a systematic literature review has identified the key skills needed for sustainable and human-centric manufacturing. It offers a comprehensive list of the abilities required to adapt to the new industrial environment. However, the study has limitations, such as its reliance on existing literature and the need for further empirical research to validate the findings. Future studies could be conducted to validate, through interviews and questionnaires, the list of skills extracted from the literature considered necessary and establish a ranking among them, also investigating the relationship between the type of skill and its sector of application. Additionally, it would be interesting to delve into the impact of learning and teaching factories on skill development. In this paper, teaching and learning factories have only been suggested as method to develop all necessary skills collectively. As seen, projects exploiting learning and teaching factories can provide a practical and safe environment for students to apply their theoretical knowledge, enhancing skill transferability and preparing them better for sustainable production challenges. Therefore, a more in-depth analysis of this theme would be beneficial.

Acknowledgment

This paper was supported by National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.1 – Call for tender No. 1409 of 14/09/2022 of Italian Ministry of University and Research funded by the European Union (NextGenerationEU), Project "TechFact - Design and adoption of Teaching Factories, Learning Spaces and Learning Activities for fostering the education of a responsible generation of engineers and technical students" (Nr. P202239XAE, CUP F53D23009290001).

This work also contributes to the advances of the Erasmus + Project "CoDEMO - Co-Creative Decision-Makers for 5.0 Organizations" (Project Nr. 101104819).

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