A New Research Agenda for Human-Centric Manufacturing: A Systematic Literature Review

R. Castagnoli, M. Cugno, S. Maroncelli, and A. Cugno

***Abstract*—The European Union recognizes Industry 5.0 as a cultural revolution that complements the fourth industrial revolution by requiring companies to implement a sustainable, resilient, and human-centric organization. This article critically analyzes the role of the human-centric approach in Industry 4.0 and 5.0 through a systematic literature review of 69 studies published between 2011 and December 2023. The results show that the human-centric approach 1) is underinvestigated in management and mainly ergonomically approached in engineering. Furthermore, it 2) enables response to the challenges of an aging population and increasing working age and improves response to acute events exogenous and endogenous to the firm. The human-centric approach also 3) positively impacts economic and social sustainability and 4) should be investigated through a transdisciplinary approach.**

***Index Terms*—Fourth industrial revolution, human-centric, Industry 4.0, Industry 5.0, systematic literature review.**

I. Introduction

RECENT macroeconomic changes have increased firms' vulnerability, requiring them to operate in exogenous acute events, such as COVID-19, economic crises, international tensions, and increasing conflicts [1]. The literature shows how Industry 4.0 technologies can help improve firms' resilience in such contexts [2] but simultaneously ignore the impact on human process optimization. This impact may be reflected in job loss, job market transformation, digital divide or exclusion, and environmental damages [1]. To overcome the adverse impacts of Industry 4.0, it is necessary to pay attention to a new approach based on human-centrism, as proposed by the cultural revolution Industry 5.0 [3]. Industry 5.0 introduces a more complex transformation than Industry 4.0, including business innovations driving the transition to a sustainable, human-centric, and resilient industry [4]. Industry 5.0 aims to transition from industrial policies for the creation of value for shareholders to industrial policies for the stakeholders' value creation, advocating for prosperity in employment (sustainable development goal (SDG) 8) [5]) and resilient economic growth (SDG 9). At the same time, respecting the planet's boundaries and placing workers' well-being (SDG 3) and training (SDG 4) are at the center of the process, reducing inequalities and (SDG 10) performing responsible production (SDG 12). In doing so, Industry 5.0 addresses emerging challenges by developing innovations from technocentric to human-centric approaches and advancing the need to balance these opposite perspectives [1], [6]. Industry 5.0 goes beyond technology, implementing a human-centric approach in firms to put core human needs and interests at the heart of the production process [4]. In this new approach, technology operates for humans, not vice versa [7].

Literature on human-centrism is increasing along with research on the transition from technocentric Industry 4.0 to human-centric Industry 5.0 [8]; however, current articles mainly analyze the topic from different disciplines addressing separate research strands. From an engineering perspective, the technological aspects of Industry 5.0 are at the center of the analysis. Related studies focus on the relationship between production automation and workers [4], on the need for a sociotechnical evolution of human beings [9], and on occupational health and safety [8]. From a management perspective, research focuses on skills and competencies [10], [11], highlighting the need to acquire, upgrade, and retrain workers' knowledge, skills, and qualifications to create better career opportunities, balance work, and personal life, and enhance job development [12]. Considering organizational and social studies, the focus is on workers' well-being, exploring strategies that include diversification of working hours, job rotation, consideration of work performance requirements, needs and qualifications of operators, and ergonomic exposure of the workplace [13], [14]. Finally, the centrality of humans is analyzed from the perspective of involving all the actors of the production system in the ideation, design, and innovation processes with a view to codesigning the change [15], increasing the efficiency of production processes through human cognitive capabilities (creativity and knowledge) and interconnecting them with intelligent systems workflows [16], [17].

However, as highlighted in [8], the role of humans in shaping the Industry 5.0 transition should be further explored. Moreover, since the effects associated with technological adoption are delayed in time, the social dimension is underrepresented [18]. Therefore, the current literature remains unclear on 1) the salient features of the articles that contribute to the development of the topic, 2) the new research strands addressed on the topic, and 3) and the uncovered gaps for future article.

This article aims to identify the role of the human-centric approach in Industry 4.0 or 5.0 with an interdisciplinary

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perspective through a domain-based systematic literature review [19], [20]. A systematic literature review helps advance a subject field [21], [22] based on a scientific, replicable, and transparent process [19]. This approach allows this article to be informative and impactful [23].

The article's originality lies in overcoming the lack of interdisciplinary analysis on the topic that may undermine the success of the transition to human-centric Industry 5.0 [18]. In fact, not considering the human-centric aspect leads to the risk of lower performance and phantom profits [24], [25].

The analysis covers all papers published between 2011 (when Industry 4.0 was introduced) and December 2023. The new research agenda uses the theory, context, characteristics, and methodology (TCCM) [23], [26] framework to reconstruct salient theoretical points in a clear, incisive, and comprehensive way. This approach leads to an updated picture of the literature and captures a research field's theoretical and empirical dimensions [27]. Moreover, the TCCM framework allows reviews to be more impactful and better reflects future research avenues [22], [28].

This article's theoretical contribution includes two main points. First, the analysis goes beyond existing literature reviews on the topic and provides the first systematic and comprehensive framework that explores the role of a human-centric approach in Industry 4.0 or 5.0 in firms. Second, the article provides a foundation for future article by identifying multiple directions.

The article might also contribute to practice as a guide for entrepreneurs, managers, and policymakers to suggest a joint adoption of new technologies and a human-centric approach to generate economic and social impact. Moreover, the research impacts several aspects of engineering management practices, shaping current industrial practices and positively affecting the quality of production processes.

The rest of this article is organized as follows. Section II describes the methodology, identifying the aim, research questions, search criteria, and inclusion/exclusion criteria. Section II also applies the search string to scientific databases, removes the duplicates, implements inclusion/exclusion criteria, realizes the analysis grid, creates the database, collects information, and analyzes the database. Section III reports the main findings, describing the salient characteristics of the literature, the main research streams addressed, and the research gaps. Section IV discusses the results, posing several propositions for a new research agenda. Finally, Section V concludes this article.

II. Methodology

This article uses a systematic qualitative review [19] of the following scientific databases: Web of Science (WoS), EBSCO, and Scopus. This article adopts a strict systematic review process to collect papers and conference proceedings and qualitatively analyses their contributions. The analysis period considers works published from 2011 (when Industry 4.0 was introduced) to December 2023.

The integration of these three databases is justified by their main characterics. WoS includes high-quality, peer-reviewed journals, identifying high academic standards and high-quality publications [29]. Scopus and WoS are authoritative international databases in social sciences [30], allowing an optimal balance between 1) good coverage of existing works, 2) convenience in retrieving papers, and 3) homogeneity of information. EBSCO is the leading provider of research databases; thus, it was selected to integrate the results.

The systematic literature review is assumed to be the best approach to synthesizing and comparing evidence from various sources [31] and reconciling a very fragmented literature [27]. This methodology is gaining exponential popularity [32] since it provides a comprehensive and unbiased literature summary, highlighting research gaps and future research directions [22]. Moreover, this methodology prevents replication of efforts in future article and significantly advances research in the chosen domain [23]. The strength of this methodology is that it performs a rigorous, transparent, and reproducible scientific design [33] that helps advance a topical field [20], [28]. In contrast, the systematic literature review methodology has two main weaknesses. The first one concerns that, if not rigorously performed through a predetermined scientific design, this approach could reduce reliability from bias [23]. However, this weakness can be overcome by adopting a review protocol, which ensures the quality of findings [34] and allows writing a well-structured framework-based systematic review. The second weakness is that the minimum sample to write a framework-based review should be between 40 and 100 articles [23]. This article respects the minimum sample, including 69 papers, even though they were published in impactful journals and as conference proceedings, as the phenomenon is new.

The article addresses the proposed research questions by analyzing studies investigating various aspects of the topic. The article's results may be particularly interesting to academics, policymakers, governments, professional associations, and practitioners [35]. In particular, the research conducts a domain-based literature review [20] in three phases, following [19], as summarized in Fig. 1.

A. *Phase 1: Planning the Review*

The first phase [19] is divided into four steps (Fig. 2).

The first step identifies the aim of the study. As mentioned, this article builds a critical understanding of the role of a human-centric approach in Industry 4.0 or 5.0, providing an interdisciplinary reinterpretation of the new scenario introduced by Industry 4.0. The following three research questions are proposed. (RQ1) What are the salient characteristics of the articles contributing to developing the topic? (RQ2) What are the new research streams addressed on the topic? (RQ3) What are the uncovered gaps for future research?

The second step identifies several keywords based on the background analysis of the literature and the author's experience. The resulting keywords are divided into Industry 4.0 and Industry 5.0 and synonyms (14 keywords) and human-centric approach and synonyms (5 keywords). Keywords are chosen by brainstorming among the authors who are experts in disciplinary and subject matter [28]. Truncation (e.g., digit$*$ = digitalization, digitization, and digital) is used in the search terms to find all relevant studies with variants of the keywords. Moreover, the keywords in each category are associated with the Boolean

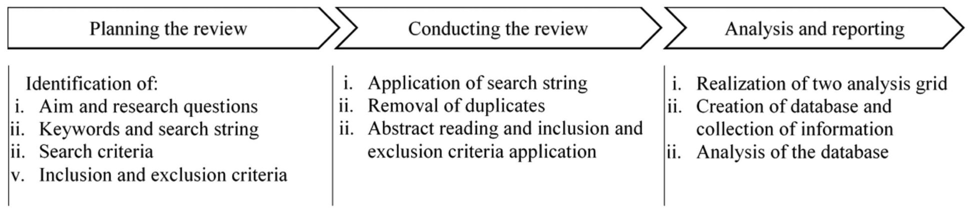

Fig. 1. Phases of the literature review. Source: Authors' elaboration.

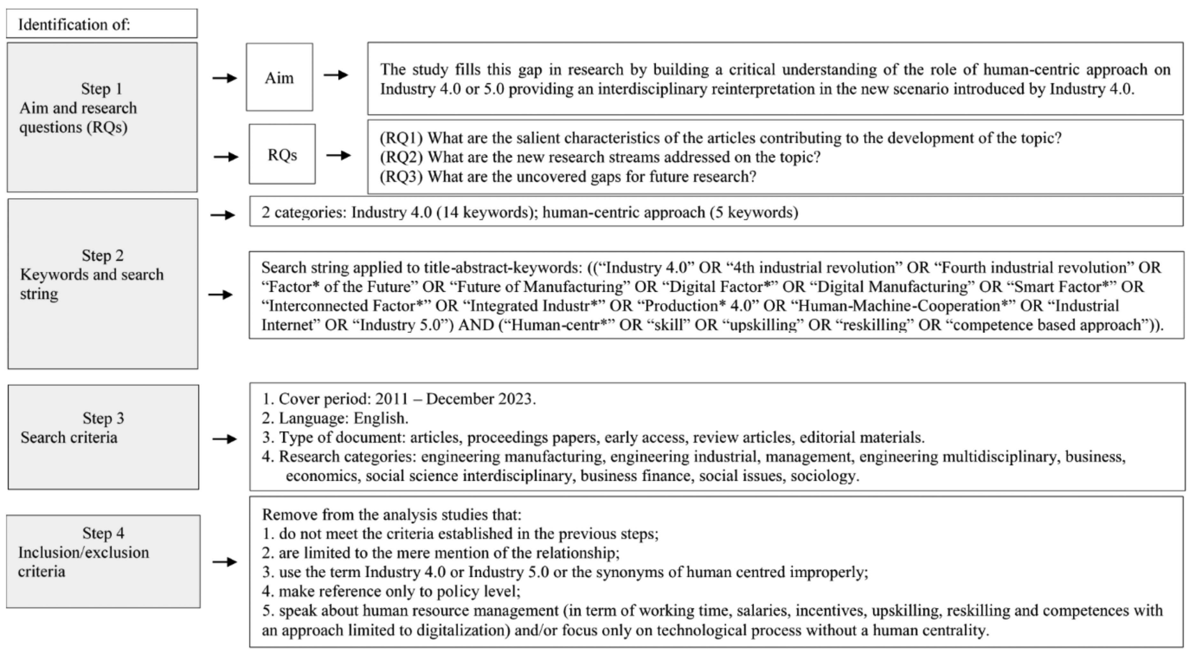

Fig. 2. Planning the review. Source: Authors' elaboration.

[36] *OR* operator to create a search string for the respective categories. Different categories of keywords are associated with the Boolean *AND* operator to develop combined search strings. Fig. 2 presents the search string used.

Their combination represents the research string applied to the title, abstract, and keywords to select the relevant articles.

The third step identifies the sample of articles selected according to the four search criteria most adopted by the literature: cover period, language, type of document, and research categories. The starting year represents the first time Industry 4.0 terms were introduced at the Hannover Fair in 2011 [37]. This approach is in line with the commonly used criteria for time selection [23] that include the conception of a construct. Even though the keywords also include Industry 4.0's synonyms, the choice to start the analysis from 2011 is based on the fact that terms used before 2011 refer to concepts that differ from Industry 4.0. The Fourth Industrial Revolution, for example, was first adopted in 1988 to identify the evolution of inventions into innovations or is associated with developing and applying nanotechnologies [38]. The choice to include only English language papers is because English is internationally used for research.

The fourth step identifies inclusion/exclusion criteria. Papers that did not fulfill the following criteria were excluded from the analysis:

1) do not meet the criteria established in the previous steps;
2) are limited to the mere mention of the relationship;
3) use the term Industry 4.0 or Industry 5.0 or the synonyms of human-centric improperly;
4) refer only to the policy level;
5) speak about human resource management (on the one hand, in terms of working time, salaries, and incentives, and, on the other hand, in terms of upskilling, reskilling, and competencies with an approach limited to digitalization) or focus only on a technological process without a human centrality.

Industry 4.0 is often incorrectly associated with digitalization (the increase in the use of information technology by an organization or a country) and digitization (the conversion of analog data such as images, videos, and text into digital form) [39]. Industry 5.0 is also occasionally wrongly associated with the concept of Society 5.0, introduced by the Japanese government, instead of the concept by the European Commission [3]. Finally, the human-centric concept and its synonyms are occasionally

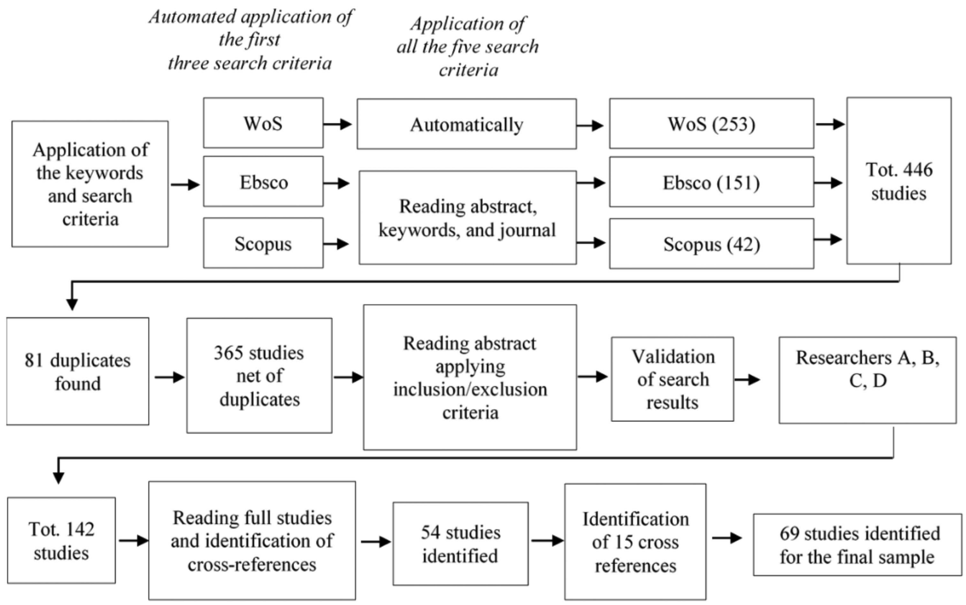

Fig. 3. Conducting the review. Source: Authors' elaboration.

referred to in contexts other than the one introduced by Industry 5.0.

B. Phase 2: Conducting the Review

The second phase [19] is divided into four steps (Fig. 3).

The first step is to apply the search strings and criteria to the three scientific databases: WoS, EBSCO, and Scopus. The selected databases help identify management studies by leading international universities. Applying the search criteria depends on the database used. With WoS, all five criteria can be applied automatically. EBSCO allows the automatic application of the first four criteria. Scopus only allows the automatic application of the first three criteria. For the selection criteria not covered in EBSCO and Scopus, the field is narrowed by reading the journal name, title, and keywords of studies. At the end of this phase, 446 studies are identified. In the second step, duplicates are eliminated (81), resulting in 365 works.

In the third step, carefully reading all the abstracts and applying the inclusion/exclusion criteria to all three databases allows 142 relevant papers to be identified. The 142 articles identified in the previous phase are read in the fourth step. After applying the inclusion/exclusion criteria, 54 studies that fully meet the proposed aim are selected.

The analysis of the abstracts, full papers, and cross-references are conducted separately by each author to limit the degree of subjectivity in applying the inclusion and exclusion criteria and, consequently, increase the reliability of the results. In this phase, 15 articles are added, leading to a final sample of 69 papers.

C. Phase 3: Analysis and Reporting

The third phase [19] is divided into three steps (Fig. 4).

In the first step, two analysis grids are constructed: a general grid containing information on the characteristics of the sample and a thematic grid identifying information on the central issues of the topic. The general grid is set up with a units-variables matrix, where the units are the individual papers of the sample indicated by the authors' names. Fig. 4 (step 1a) presents the reported variables, including authors, year of publication, journal, number of authors, analyzed country, journal ranking, approach (conceptual/empirical), research method (qualitative/quantitative/mixed-methods), research design/technique (case study, test case, interviews, survey, focus group, literature review, experiment, and other), and units of analysis.

The thematic grid is also set up with a units-variables matrix, where the units are the individual papers in the sample indicated by the authors' names. The variables include aim, research questions/hypotheses, research gaps, results, emphasis of the discussion (Industry 4.0/Industry 5.0), disciplines, research fields, level of analysis (value chain/ecosystems), perspective (workers/firms), terms related to the topic, focus (product/process), external/internal shocks, barriers, drivers, cross-references, social implications, economic implications, and tools to apply human-centric approach [Fig. 4(step 1b)].

In the second step, data from the two analysis grids are collected, and the two grids are integrated into an Excel database to analyze the main variables.

In the third step, the information from this database is processed to answer RQ1 (see Section III-A) and RQ2 (see Section III-B). The general and thematic grid variables are identified from the classification used in the literature [40]. The data analysis process is implemented manually (for descriptive and thematic analyses) by reading the articles in the database and classifying the content for each dimension of the two analysis grids through a consensus conference between the authors.

Based on the responses to RQ1 and RQ2 and using the TCCM framework [21] (see Section III-C), research gaps are identified,

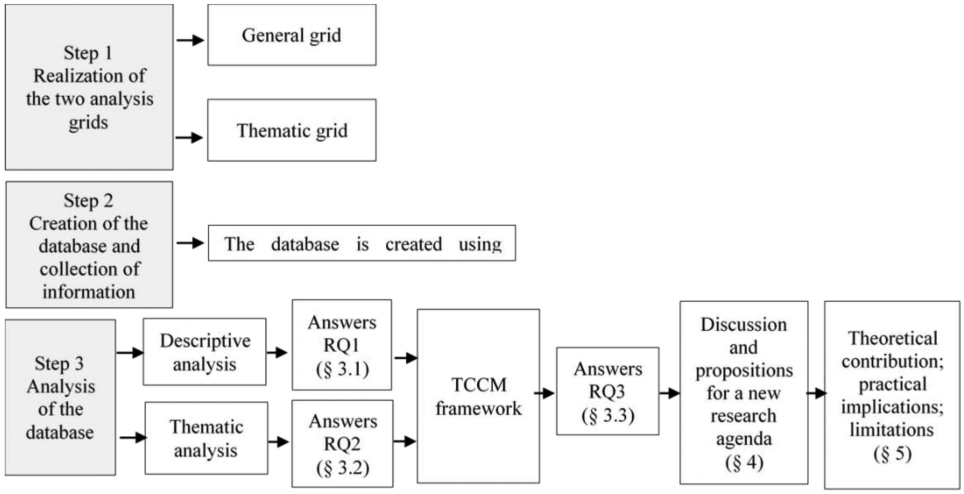

Fig. 4. Analysis and reporting. Source: Authors' elaboration.

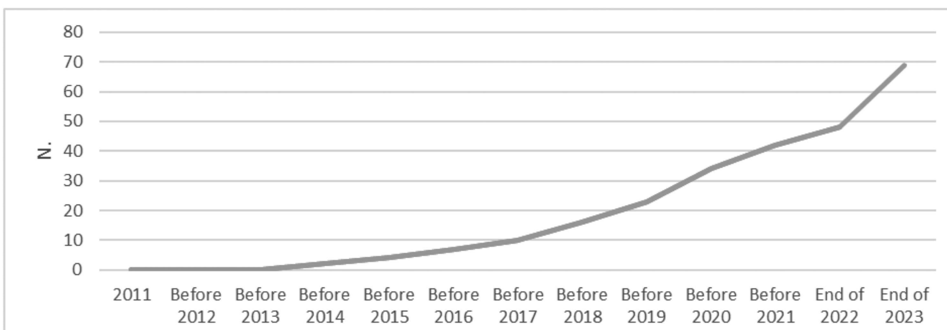

Fig. 5. Year of publication of the analyzed articles. Source: Authors' elaboration.

answering RQ3. The discussion points out propositions for a new research agenda, following [41] (see Section IV), and the conclusion highlights theoretical contribution, practical implications, and limitations (see Section V).

III. Findings

The results from the 69 sampled studies allow a suitable answering of the research questions 1 (Section III-A), 2 (Section III-A), and 3 (Section III-C). As mentioned above, the research questions are as follows: (RQ1) What are the salient characteristics of the articles contributing to developing the topic? (RQ2) What are the new research streams addressed on the topic? (RQ3) What are the uncovered gaps for future research?

A. Salient Characteristics of the Literature

The descriptive analysis examines the information collected through the general grid. Fig. 5 shows that studies began to be published in 2014 (two articles) and increased significantly from 2018. The phenomenon may be surprising since the human-centric concept was introduced by the European Commission [3]; however, as early as 2016, the Japanese government referred to the human-centric society within the Society 5.0 industrial plan. The analysis shows that the studies that explicitly refer to Industry 5.0 were published after 2020 and significantly increased in 2023; all other articles refer to Industry 4.0 instead.

Table I shows the journals (31) and major conferences (9) investigating the topic. Among the journals, 34 studies are in the Chartered Association of Business Schools (2020) international ranking; CABS is an international business school ranking that evaluates scientific journals from an interdisciplinary perspective on a scale ranging from 1 as the lowest to 4∗ as the highest score. The ranked studies include 9 with a ranking of 1, 12 with a ranking of 2, and 15 with a ranking of 3. In almost all cases, the publications refer to different conferences and journals, except for the International Journal of Production Research (13 papers), Computers and Industrial Engineering (9 papers), Journal of Manufacturing Systems (3 papers), and the Journal of Intelligent Manufacturing (3 papers).

Table II shows the investigative approaches, methods, and techniques used by the articles analyzed. Regarding the approach, 44 articles are empirical and 25 are nonempirical. This article refers to [105], distinguishing nonempirical articles into theory, review, or commentary/critique. The analyzed research investigates the phenomenon mainly through case studies and

TABLE I
JOURNALS OF PUBLICATION OF THE ANALYZED ARTICLES

Journals/conferences	*Ranking (CABS, 2020)*	*Number of articles*	*Authors*
12th Global Conference on Sustainable Manufacturing	Conference	1	[42]
29th CIRP Design 2019	Conference	1	[43]
Advanced Engineering Informatics	-	2	[44], [45]
AI & SOCIETY	-	1	[46]
Annals of Operations Research	3 ABS	1	[47]
APMS 2015: Advances in Production Management Systems: Innovative Production Management Toward Sustainable Growth	-	1	[48]
Applied Science	-	2	[49], [50]
Capital & Class	-	1	[51]
CIE46 Proceedings	Conference	1	[52]
CIRP Annals Manufacturing Technology	Conference	2	[53], [54]
Computers & Industrial Engineering	2 ABS	9	[55], [56], [57], [58], [59], [60], [61], [62], [63]
Economics & Sociology	1 ABS	1	[64]
Ergonomics	3 ABS	1	[65]
HCI International 2019–Late Breaking Papers	Conference	1	[66]
IEEE 2nd International Forum on Research and Technologies for Society and Industry Leveraging a Better Tomorrow (RTSI)	Conference	1	[67]
IFIP International Conference on Advances in Production Management Systems	Conference	1	[52]
International IFIP WG 5.7 Conference on Advances in Production Management Systems (APMS)	Conference	1	[68]
International Journal of Computer Integrated Manufacturing	2 ABS	2	[69]; [70]
International Journal of Industrial Ergonomics	1 ABS	1	[71]
International Journal of Logistics Research and Applications	-	1	[50]
International Journal of Production Research	3 ABS	13	[8]; [24]; [72]; [73]; [74]; [75];[76]; [77]; [78]; [79]; [80]; [81]; [82]
International Journal on Advances in Intelligent Systems	-	1	[83]
Journal of Industrial Information Integration	-	1	[84]
Journal of Intelligent Manufacturing	1 ABS	3	[85]; [86]; [87]
Journal of Knowledge Management	-	1	[88]
Journal of Manufacturing Science and Engineering Transactions of the Asme	-	1	[89]
Journal of Manufacturing Systems	1 ABS	3	[90]; [91]; [18]
Journal of the Knowledge Economy	-	1	[92]
Management Revue	-	1	[93]
Organizacija	-	1	[4]
Procedia Manufacturing	-	1	[94]
Procedia Technology	-	1	[95]
Proceedings of the International Conference on Intellectual Capital, Knowledge Management & Organizational Learning	Conference	1	[96]
Production & Manufacturing Research	-	1	[97]
Robotics and Computer Integrated Manufacturing	-	1	[98]
Service Oriented, Holonic, and Multi-agent Manufacturing Systems for the Industry of the Future	-	1	[99]
Structural Change and Economic Dynamics	2 ABS	1	[100]
Technology in Society	-	2	[101]; [102]
The International Journal of Advanced Manufacturing Technology	-	1	[103]
Transdisciplinary Engineering Methods for Social Innovation of Industry 4.0	-	1	[104]
Total		69	

Source: Authors' elaboration

TABLE II
APPROACHES, METHODS, AND INVESTIGATION TECHNIQUES USED BY THE ANALYZED ARTICLES

Approaches	*Methods*	*Investigation techniques*	*Number of articles*	*Authors*
Empirical	Quali-quantitative	Test case	6	[65]; [96]; [84]; [92]; [82]; [89]
		Mixed-methods	1	[106]
	Qualitative	Test case	9	[47], [66], [91], [94], [101], [107], [108], [109], [55]
		Case study	3	[68], [76], [80]
		Mixed-methods	4	[55], [110], [111], [112]
		Interviews	2	[78], [113]
	Quantitative	Test case	12	[72], [87], [95], [103], [104], [114], [115], [116], [117], [118], [54], [70]
		Survey	1	[46]
		Experiments	2	[99],[74]
		Mixed-methods	3	[119], [120], [121]
		Secondary data	1	[88]
			(44)	
Non-empirical	-	Commentary/critique	8	[52], [64], [67], [90], [93], [122], [123], [124], [64]
	Quali-quantitative	Systematic literature review	3	[8], [98], [125]
	Qualitative	Commentary/critique	2	[51], [126]
		Systematic literature review	5	[4], [45], [60], [81], [86]
		Review of use cases	1	[127]
		Mixed-methods	1	[59]
	Quantitative	Literature review	5	[18], [18], [50], [128], [129], [130]
			(25)	
Total			69	

Source: Authors' elaboration

test cases. The latter indicates the validation of a framework by industrial application of a predominantly engineering nature. Few studies use surveys or secondary data (1 out of 69 articles).

B. Main Research Streams Addressed in the Literature

The following section reports the disciplines exploring the topic, and the existing research strands for each discipline are identified. Table III shows that the studies identified on the topic are predominantly from the engineering field (56 out of 69 studies), compared with 5 studies from the management field, 3 in journals and conferences from the sociological field, and 1 from the economic field. Finally, four articles are interdisciplinary. Although the disciplines involved differ, some research strands, later identified by the authors, cover multiple disciplines, namely ergonomics and organization. The following section describes Table III by research strands.

The research strand on ergonomics is analyzed by more disciplines, namely engineering (17 studies) and interdisciplinary (1 study). Engineering mainly focuses on optimizing simultaneously overall system performance and human well-being in different work contexts [129]. This aspect is mainly related to design-oriented practices for improving compatibility, effectiveness, safety, and quality of life [129]. According to the interdisciplinary discipline, technology increases time and cost savings and improves ergonomics to support human-centered design [69].

Existing studies emphasize the urgent need to consider the human factor in Industry 4.0 to avoid underperforming and nonoptimized systems, technology rejection, and negative consequences on human workers [25], [125], [129]. This topic mainly gains attention in 2023 (Cfr. Table V). Despite effective differences between the terms ergonomics and human factors, these are often used interchangeably [124].

TABLE III
DISCIPLINES AND RESEARCH STRANDS COVERED BY ANALYZED ARTICLES

Disciplines	*Research strands*	*Number of articles*	*Authors*
Engineering	Ergonomics	17	[65], [67], [76], [78], [80], [82], [87], [111], [115], [116], [117], [118], [120], [125], [129], [132], [133]
	Process design	11	[127], [134], [120], [90], [86], [60], [91],[101],[70], [112], [135]
	Work design and organization	22	[18], [47], [52], [54], [55], [66], [72], [74], [81], [94], [95], [98], [99], [103], [106], [108], [113], [114], [122], [123], [126], [136]
	Production design	2	[107], [121]
	Ecosystem development	1	[92]
	Social sustainability	1	[59]
	Socio-technical systems	2	[8], [124]
		(56)	
Management	Human resource and knowledge management	1	[88]
	Organization	4	[4], [50], [68], [93]
		(5)	
Sociology	Organization	3	[46], [51], [64]
		(3)	
Economics	Organizzation changes	1	[110]
		(1)	
Interdisciplinary	Ergonomics	1	[69]
	Organization	3	[96], [128], [130]
		(4)	
Total		69	

Source: Authors' elaboration

The process design research assumes that human-centered production should meet human needs in the workplace with workers' safety and health at the base and self-realization at the apex [90]. This situation is possible by adopting Industry 4.0 technologies, which are oriented to innovative designs for business models and new purposes, approaches, and capabilities [4].

The organization research strand is analyzed by management (4 studies), sociology (3 studies), economics (1 study), and interdisciplinary (3 studies) disciplines and as a mixed research strand on work design and organization by engineering discipline (22 studies). The organization management discipline is mainly distinguished on four macro topics: technological application, human resources and workers, education, and operation management [4]. In contrast, the systematic literature review by [4] shows a lack of understanding concerning the role of Industry 5.0 in firms' management. The sociology discipline explores organization research, assuming that technological innovations introduce organizational and commercial changes that create new opportunities, risks, and threats to people's lives [64]. This approach requires social and work policies based on preventing threats to social quality, creating the possibility of sustainable development [46]. Discipline on economics explores this research strand, focusing on organizational changes introduced by 4.0 technologies, reducing workers' autonomy and increasing forms of control [110]. Interdisciplinary disciplines explore the organization research strand, focusing on difficulties in inserting technologies inside organizations. Data, information, and knowledge exchange inside the organization must be explored more deeply [128]. Finally, engineering studies on work design and organization research (22 studies) propose a mixed research strand focusing on the role of workers, or operators, inside new factories and on the new organization required to support workers. Concerning the first aspect, Industry 4.0 and 5.0 operators should be more resilient to shocks affecting their work and workplaces [123]. Referring to the second aspect, the application of Industry 4.0 technologies identifies, through key performance indicators, the misalignments between strategies and operations [108], improving organization flexibility.

The production design research strand focuses on the possibility of industrial wearable systems to decrease errors and improve interaction in decision-making, feedback, and execution of humans–close-loop human–machine interaction, decisions, feedback, and execution [107], [131].

The ecosystem development research strand is analyzed by engineering studies as a required starting point for an open innovation process able to realize smart, sustainable, and inclusive solutions typical of Industry 5.0 [92].

The social sustainability research strand explored by engineering studies indicates how Industry 5.0 should focus on work-life balance, physical and psychological well-being, aging, and diversity [59].

The management discipline investigates the human resource and knowledge management research strand, which explores firms' engagement in diversity, inclusion, and people empowerment influences performance [88].

The body of knowledge is then deepened by describing the level of analysis (whether ecosystem or value chain level), value

TABLE IV
LEVEL OF ANALYSIS AND STAGES OF THE VALUE CHAIN/LEVELS INVESTIGATED BY THE ANALYZED ARTICLES

Level of analysis	*Value chain phases*	*Number of articles*	*Authors*
Ecosystem	Macro, meso, micro	1 (1)	[92]
Value chain	Knowledge acquisition/decision making	1	[128]
	Assembly line	7	[82], [95], [98], [115], [117], [118], [132]
	Decision making	1	[114]
	Process design	4	[46], [86], [101], [136]
	Product design	4	[65], [107], [109], [111]
	Several phases	18	[51], [52], [64], [66], [88], [88], [90], [91], [93], [96], [112], [119], [122], [123], [124], [126], [129], [137]
	Operations	2	[4],[125]
	Internal logistics	5	[8], [50], [113], [116], [138]
	Workplaces	1	[130]
	Maintainance	3	[47], [78], [108]
	Organization	2	[99], [110]
	Production	17	[18], [45], [54], [55], [60], [67], [72], [76], [80], [81], [103], [106], [109], [119], [121], [127], [133]
	Shop floor	3 (68)	[68], [87], [94]
	Total	69	

Source: Authors' elaboration

chain phases explored, shocks identified, enabling factors found, economic implications mapped, barriers to the defined implementation, and perspectives adopted (focused on firms and/or workers).

Among the analyzed studies, 68 out of 69 papers investigate the role of the human-centric approach in Industry 4.0 or 5.0 at different value chain stages (Table IV). In particular, 18 papers investigate the effect of change at different stages, followed by 17 studies specifically investigating production. Only one paper analyzes how the ecosystem changes at the micro, meso, and macro levels.

Only 11 papers make explicit the role of various exogenous or endogenous shocks in accelerating the transition to a human-centric approach. These are mostly exogenous shocks related to the pandemic crisis, economic crises, and social challenges, such as an aging population and the consequent increase in working age (Table V). A set of studies (37) explore the role of enabling factors that can incentivize the application of the human-centric approach in firms. Human-centricity improves workers' physical and psychological well-being, equity, and inclusion. Some studies (25) identify the economic opportunities that can arise from adopting a more human-centric approach, both in terms of increased effectiveness and efficiencies and as an enhancement of human capital and productivity. A limited number of papers identify some obstacles to implementing this approach, primarily referring to issues related to privacy concerns and workers' cognitive and value resistance to new technologies.

In most cases, the analyzed articles adopt a perspective on how the human-centric approach enables better strategic-operational management of firms (Table V). Only 9 articles use a perspective related only to the effects on individual workers, while 15 studies consider both approaches jointly.

C. Research Gaps: The TCCM Framework

The sample of articles examines the role of the human-centric approach in Industry 4.0 and 5.0 in firms, showing increased interest in the topic in the last 3 years. In particular, four disciplines address the relationship with an engineering, managerial, sociological, and economic perspective. Moreover, some studies also address the research topic through an interdisciplinary perspective; however, the literature remains unclear. Future article investigate the economic and social effects and challenges further. The following sections present existing gaps and emerging lines of research using the TCCM framework, which can help develop theoretical highlights in a clear, incisive, and comprehensive manner [26], [142]. TCCM is one of the most widely used frameworks due to its versatility and comprehensibility [143]. It is distinguished by theory (T), context (C), characteristics (C), and methods (M). Theories recognize theoretical underpinnings explaining inter-relationships between constructs. Contexts summarize circumstances shaping the research setting. Characteristics map the elements of a construct and their relationship with other variables of interest. Methods report samples, measurements, research designs, and analytical tools [143]. The following sections answer RQ3, identifying future research lines.

1) Theory: The systematic literature review shows, through an exploratory analysis of a multidisciplinary sample, that the topic is deepened by the following disciplines: engineering, management, economics, and sociology. The studies conducted do not directly reference specific strands of research, but different strands are identified through this article's analysis. There is a lack of theoretical anchorage to understand the areas already investigated and the definitions, tools, and gaps in the different research strands. Existing studies mainly belong to the engineering discipline, which, through industrial test cases,

TABLE V
SHOCKS, ENABLING FACTORS, ECONOMIC IMPLICATIONS, AND BARRIERS TO IMPLEMENTING THE HUMAN-CENTRIC APPROACH HIGHLIGHTED BY THE ANALYZED ARTICLES

Shocks	*Number of articles*	*Authors*
Increased requirements for work security	1	[129]
Increased resilience required by Covid-19 pandemic	2	[47], [88]
Social challenges requirements	2	[114], [122]
Firms' internal problems	2	[108], [119]
Recovery from economic crises	2	[90], [110]
Technological change	2	[87], [124]
	(11)	
Enabling factors	*Number of articles*	*Authors*
Physical and psychological well-being of workers and knowledge and skills	16	[8], [18], [50], [52], [67], [70], [76], [99], [103], [106], [111], [116], [123], [133], [137], [138]
Fostering equity and inclusion	11	[60], [72], [78], [80], [88], [113], [114], [117], [118], [122], [139]
Fostering ethics, value orientation, and sustainability	2	[112], [120]
Improving the security of systems	2	[93], [129]
Increasing workers' knowledge	3	[68], [128], [140]
Sustainable production and consumption	1	[86]
Allowing the transition from industrial to digital capitalism	1	[110]
Enabling systemic economic development	1	[92]
	(37)	
Economic implications	*Number of articles*	*Authors*
Increasing firms' performance, efficiency, and productivity	8	[68], [70], [82], [88], [103], [124], [128], [137]
Improving the overall performance of the work environment	3	[76], [129], [132]
Increasing service offerings	1	[92]
Optimizing internal logistics	1	[50]
Enhancing human efficiency	7	[8], [66], [72], [87], [114], [122], [123]
Reducing long-term costs related to absenteeism and illness	1	[113]
Reducing costs related to warehouse	1	[116]
Reducing maintenance costs	1	[78]
Optimization of investment costs	1	[117]
Improving opportunities for occupability for people with disabilities	1	[118]
	(25)	
Barriers to implementation	*Number of articles*	*Authors*
Workers' privacy issues	3	[66], [125], [135]
Problems of cognitive-value acceptance	3	[47], [90], [124]
Focus on issues: unemployment, non-standard work	1	[64]
Risk of costs increasing	1	[76]
Lack of skills and competences	1	[121]
Risk of increasing work-related stress	1	[112]
	(10)	

Source: Authors' elaboration

investigates the opportunities that adopting human-centric technologies has for improving workers' well-being, increasing firms' productivity, and overall system management. Despite the solid multidisciplinary value of these implications, the phenomenon remains poorly investigated from economic, managerial, and sociological perspectives.

2) Context: In terms of geographic context, the article highlights that the work mainly focuses on developed countries, notably Italy [92], [108], [109], [110], [114], [115]. This concentration might undermine the results with an unbalanced geographical context focused only on developed countries. However, the implementation of Industry 4.0 technologies is very different

TABLE VI
PERSPECTIVE OF ANALYSIS ADOPTED BY THE ANALYZED ARTICLES

Perspective	*Number of articles*	*Authors*
Firm	44	[4], [8], [47], [50], [51], [54], [55], [60], [64], [65], [70], [78], [81], [86], [88], [90], [91], [92], [93], [94], [95], [99], [101], [103], [107], [108], [109], [111], [112], [115], [116], [117], [120], [124], [125], [126], [127], [129], [132], [134], [136], [137], [140], [141]
Workers	9	[18], [72], [80], [87], [113], [114], [118], [121], [128]
Firm and workers	15	[46], [52], [66], [67], [68], [76], [82], [98], [106], [119], [122], [123], [130], [133], [138]
Total	68	

Source: Authors' elaboration

in developing countries [144], which, as emerging economies, are characterized by a differentiation of Industry 4.0-related opportunities for the country's business development.

From the perspective of the industrial context, existing works focus on the manufacturing sector, with a focus on aerospace [92], [108] and automotive [134], [115]. The prevalence of research in these areas is due to their high strategic relevance and technological intensity; however, a lack of analyses in low-intensive industries might have different implications.

3) Characteristics: The analyses of the sample of articles identified show that some exogenous or endogenous challenges have accelerated the need to adopt a human-centric approach. Exogenous challenges include the pandemic crisis [47], [88], the economic crisis of 2008 [90], [110], social challenges related to an aging population and consequently increasing working age [114], [122], and increased obligations for job security [129]. Endogenous challenges include internal business challenges [108], [120]. The role of national, European, and international policies toward greater adoption of the human-centric approach appears to be little investigated.

Many studies also highlight several factors that can facilitate the implementation of Industry 4.0 technologies and the transition to more human-centric enterprises. Such research focuses mainly on the physical, psychological, and cognitive benefits of workers [52], [123], among others. Additional drivers include improved equity and inclusion and, more generally, social sustainability [88], [120], more sustainable production and consumption [86], and systemic economic development [92].

Few articles focus on obstacles to implementing this approach. The main ones include problems related to the protection of workers' privacy [66], [139] and difficulties with workers' cognitive-value acceptance of technology [47], [90].

Finally, the literature shows that coupling a human-centric approach with adopting Industry 4.0 technologies leads to higher economic performance than can be achieved through technology adoption alone. The effect is predominantly due to increased service offerings [92], optimization of internal logistics [50], increased workers' productivity [66], [114], [122], [128], and reduced errors [123]. To date, the economic impact of this approach in terms of reduced costs and/or increased revenues is still unexplored.

4) Method: The literature delves into this issue with different approaches, methods, and techniques, with a prevalence of industrial test cases and a notable minority of studies conducted through surveys [46], [120] or quantitative analysis of secondary data [88]. Moreover, most studies focus on a firm's perspective (45 studies, see Table VI); only 9 studies focus on the role of workers [114], [128], and 15 studies focus on both workers' and firms' perspectives. Therefore, studies focusing on the role of workers at a microlevel are lacking.

IV. DISCUSSION AND NEW RESEARCH AGENDA

The systematic literature review, through the TCCM framework [22], points out the relevance of the human-centric approach in Industry 4.0 and 5.0 firms.

From the analysis of knowledge gaps and conflicting results in the literature to date, the following sections outline eight propositions (P) related to theory, context, characteristics, and method that can be used in future article, as summarized in Fig. 6.

Concerning theory, each discipline addressing the topic of the human-centric approach in Industry 4.0 and 5.0 must still anchor to a theory to reinforce its analyses.

Engineering articles must refer to design theory to improve process, product, and workplace design in a human-centric manner [15]. Consequently, the following proposition is stated.

P1: Design theory will help achieve a more human-centric technological implementation in engineering.

Management and economic disciplines must anchor themselves to the common organizational theory, which might help to combine efficiency and human-centricity [4], [50]. Therefore, the following proposition is assumed.

P2: Organizational theory will help balance efficiency and human-centricity development in management and economic disciplines.

Sociology must approach the topic's analysis from the perspective of sociotechnical systems, helping to match technology, relationships, and organizational models [8], [124]. Accordingly, the following proposition is defined.

P3: Sociotechnical systems theory will help achieve a balanced integration between technological adoption, relationship redefinition, and reinterpretation of the organizations' roles in the sociological discipline.

Moreover, industrial ecology is a theory that may be common to all the considered disciplines (with an interdisciplinary perspective, or as some authors point out, a transdisciplinary engineering [47]), allowing for the development of ecosystems

TCCM	*Propositions' numbers*	*Dimensions*	*Impact (+/-)*	*Effects*
Theory	P1	Design theory in engineering	+	Human-centric technological implementation
	P2	Organizational theory in management and economics	+	The balance between efficiency and human-centricity
	P3	Socio-technical systems theory in sociology	+	Balanced integration between technological adoption, relationship redefinition, and reinterpretation of the organizations' roles
	P4	Industrial ecology in an interdisciplinary approach	+	Balance between different disciplines and theories for an improved human-centric approach in Industry 4.0 and Industry 5.0 firms
Context	P5	Weak economic infrastructures, skills, and culture in less economically developed areas in emerging countries	-	Human-centric approach
	P6	Less skills and lower habits in managing new technologies in low-tech industries	-	Human-centric approach
Characteristics	P7	Protection of workers' privacy and difficulties with workers' cognitive-value acceptance of technology	-	Firms' propensity to implement 4.0 technologies with a human-centric approach
Method	P8	More conscious and active role of workers in technological implementation	+	Human-centric approach

Fig. 6. Propositions for future research. Source: Authors' elaboration.

leading to the development of the human-centric approach in firms [92]. This approach might help extend engineering approaches by incorporating methodologies and theories peculiar to the social sciences to gain the necessary knowledge of users and context and implement technological and non-technological solutions. Therefore, the following proposition is developed.

P4: Industrial ecology theory will help to find a balance between different disciplines and theories for an improved human-centric approach in Industry 4.0 and 5.0 firms in the interdisciplinary debate.

Concerning context, geographical and industrial contexts should be further analyzed.

Studies on geographical context should deepen the role of less analyzed countries, such as less economically developed areas. Compared with developed countries, firms might have weaker results from technological adoption of the human-centric approach due to less economic infrastructures, skills, and culture related to the human-centric approach [144]. Thus, the following proposition is proposed.

P5: Less economically developed areas in emerging countries will have more difficulties adopting a human-centric approach due to weak economic infrastructures, skills, and culture.

Studies in an industrial context should focus on lower technology-intensive industries, which might be weaker than high-tech industries in adopting a human-centric approach due to fewer skills and lower habits in managing new technologies [92]. Consequently, the following proposition is derived.

P6: Low-tech industries will have more difficulties adopting a human-centric approach due to fewer skills and lower habits in managing new technologies.

Concerning characteristics, future analyses on the topic should be conducted on obstacles to the human-centric approach that might be mainly related to the protection of workers' privacy [139], [66] and difficulties with workers' cognitive-value acceptance of technology [47], [90]. Hence, the following proposition is presented.

P7: Issues on protecting workers' privacy and difficulties with workers' cognitive-value acceptance of technology will risk hindering firms' propensity to implement Industry 4.0 technologies with a human-centric approach.

Concerning method, there is a need for more surveys [120] or quantitative analysis of secondary data [88] focusing on the role of workers [46], which is essential in the conscious adoption of technologies allowing a more effective human-centric approach [114], [128]. Accordingly, the following proposition is proposed.

P8: Workers' more conscious and active role in technological implementation will lead to a greater human-centric approach.

V. Conclusion

The article contributes to the literature on the human-centric approach in Industry 4.0 and 5.0 by identifying characteristics (RQ1), research streams (RQ2), and gaps (RQ3) in existing studies. This article conducted a systematic literature review on 69 multidisciplinary studies published between 2011 and December 2023, analyzed through the TCCM framework. The answer to the research questions outlines eight propositions that represent the basic assumptions for defining valuable engineering management practice implications that challenge current industrial practices.

The findings of the descriptive analysis (answering RQ1) show that the report has attracted increasing interest from 2018 in engineering, management, economic, and social disciplines; however, few papers use an interdisciplinary approach. The papers thoroughly explore the topic through test cases, case studies, and conceptual approaches.

The thematic analysis results (answering RQ2) show that the papers are not traced back to reference theories but can augment state-of-the-art literature by investigating how applying the human-centric approach to Industry 4.0 or 5.0 firms allows responding to global challenges. Such challenges include the aging population and working age, operating during exogenous acute events (COVID-19 and economic crises), or internal business realities. Implementing human-centric aspects within Industry 4.0 firms also allows for better economic and social sustainability, albeit with issues of workers' privacy and cultural-value acceptance by workers.

Gaps in the literature are identified through the TCCM framework (answering RQ3). A gap in anchoring different disciplines to specific theories and a gap in interdisciplinary studies is identified within theory development. Two gaps are identified within context: emerging countries and low-tech industries. Within characteristics, the main gap identified concerns the role of factors hindering Industry 4.0 technologies implementation and the human-centric transition. Finally, the identified lacking point for method is related to surveys and secondary data on the workers' role.

From identifying gaps, eight propositions are identified (four concerning theory, two concerning context, one concerning characteristics, and one for method) that make it possible to recognize specific valuable practical implications for engineering management practices that challenge current industrial practices.

A. Practical Implications

This article provides a useful tool for reconstructing the state-of-the-art and future lines of research for academics. Moreover, the article can be a practical guide for firms who want to adopt a human-centric approach according to Industry 4.0 and 5.0 paradigms, professional associations to define roadmaps and develop guidelines, standards, and toolboxes that can support a joint adoption of new technologies and human-centric approach, and governments to identify policies and supportive regulations for a human-centric transition.

Research suggests that Industry 4.0 technologies in firms can enable a human-centric system that may generate several impacts. The economic effect is measured in terms of increased performance of work systems, service delivery, value chain optimization, sustainable production, and human efficiency; social, through increased workers' knowledge, physical and psychological well-being, and inclusion and equity. These positive impacts go in the direction evoked by international institutions and are detailed in the SDGs 3, 4, 8, 9, 10, and 12 of the UN 2030 Agenda.

In particular, future firms' strategies, governments' policies, and standards might be based on three main focuses: cultural change, redesign, and empowerment.

1) Cultural Change: The human-centric approach requires a cultural change toward transdisciplinary engineering based on industrial ecology, which opens up a dialog between different perspectives on human-centrism. This situation implies a first main challenge (C) to current industrial practices in engineering management:

C1: Passing from traditional production models based on linear processes to integrated production models (industrial ecosystems) through perspectives oriented to sustainability (including the social axis, currently underinvestigated) and organization.

C1 means to rethink, in industrial ecosystems' production processes, more sustainable value and supply chains through value cocreation mechanisms with different stakeholders [147], with specific attention to nontraditional ones (i.e., civil society).

Moreover, cultural change might be developed upstream and downstream of technology adoption.

Upstream, the human-centric approach, to be fully implemented in Industry 4.0 contexts, insists on a cognitive and cultural acceptance of technology by workers [47], [90]. On the one hand, knowledge and skills to interface with technology must be developed in this direction [111]. On the other hand, trust and readiness for change are required to transition from a simple human–machine relationship to a true symbiosis [52], where humans and robots may also create mixed teams [145]. Downstream, the human-centric approach should be oriented to overcome the conflict between technological adoption's positive and negative aspects. The recurring negative aspects include privacy concerns [66], [139], unemployment and nonstandard work [64], and forms of work control [64]. The most cited positive effects mainly concern the ability of technologies to foster equity and inclusion [88], ethics and value orientation [119], and human efficiency [66], [123].

To balance these issues, this article helps identify best practices in human-centric approach implementation in specific advanced contexts (developed countries and high-tech industries) that should be used as models to be adapted in new, weaker contexts (developing countries and low-tech industries). This situation implies a second challenge to current industrial practices in engineering management:

C2: To be open to existing transversal best practices to implement the emerging phenomenon of Industry 5.0 instead of being focused on specific and isolated contexts.

2) Redesign: Industry 4.0 and adopting enabling technologies can leverage firms' work redesign and reorganization at different levels. On this aspect prevails two contrasting perspectives. The first perspective pays attention to the increased safety and health of workplaces [90] thanks to technologies and a human-centric approach. The second perspective alerts on reduced workers' autonomy and increased forms of control [110].

To balance these issues, this article suggests that engineering management redesign and codevelop processes involving workers at each firm level to augment awareness of technologies and human-centric approach and, consequently, acceptability. This approach can increase human–machine integration in production processes, implying the following strong challenge to current industrial practices:

C3: To pass from a focus based on products or processes to a focus based on workers.

This change also asks to reorient workplace innovation to adapt working spaces and stations to the emerging issues of diversity inclusion and equity [59] (such as age, gender, ability, and culture), work-life balance constraints, sustainability, and well-being [13], [14]. This approach implies the following challenge to current industrial practices in engineering management:

C4: To move from efficiency-based to responsible-oriented workplaces in which ergonomics matches with the attention to human needs at individual and societal level.

3) Empowerment: Industry 4.0 technologies introduce a higher degree of complexity within the firms and demand greater flexibility in personnel management models, challenging the ideal type of manager based on calculation, capitalization of previous experience, and exercising hierarchical power. The human-centric approach, in response, introduces the possibility for managers to increase the quantity, quality, and selection of information useful for decision-making [114]. Managers should have the right skills and competencies to manage this increased complexity of information and knowledge, and insights into using it to its full potential are still lacking [128].

In this direction, the results imply that specific metrics should be defined based on health, ergonomics, security [8], efficiency, performance [108], human needs, and satisfaction [4]. This situation represents an additional challenge to current industrial practices in engineering management:

C5: To pass from standardization to personalization of work practices.

This article's systematic literature review identifies keywords to establish a common language between disciplines on an emerging phenomenon, which 1) firms might use to participate in international, European, and national finance projects, 2) professional associations can use this article's findings to define roadmaps and develop supportive guidelines and standards for adopting a human-centric approach in Industry 4.0 and 5.0; and 3) finally, governments can use this article's results to define appropriate incentives and policies to support and orient human-centric transition in firms according to societal priorities.

These aspects positively impact the quality of engineering management practices and are useful tools to orient future industrial validation of human-centric approach implementation in Industry 4.0 and 5.0 firms. Such implementation aims to integrate and enrich the shared knowledge of engineering management that is useful for entrepreneurs, managers, professional associations, and policymakers.

B. Limitations

Since Industry 5.0 is still an emerging phenomenon, the sample includes articles published in journals with lower international rankings and conference proceedings to allow for more studies to understand the transformations. However, many studies on the topic will be published in the following months, so it would be useful to revisit the analysis in the future.

Furthermore, the analysis is based on an emerging phenomenon, which partly limits the theoretical comprehension of the topic. Future articles might overcome this limitation through phenomenon-based research. This approach represents an important early phase in scientific inquiry, aiming at capturing, describing, documenting, and conceptualizing the phenomenon so that appropriate theorizing can proceed [146]. Moreover, since the topic is still emerging, existing literature and the identified propositions still have an explorative approach. Therefore, future articles should conduct confirmatory analysis on each area identified.

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