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RESEARCH ARTICLE

Defining human-centricity in Industry 5.0 and assessing the readiness of ergonomics/human factors communities in UK

Setia Hermawati, Rhea Correa, Mrinal Mohan, Glyn Lawson and Robert Houghton

Human Factors Research Group, Mechanical, Materials and Manufacturing Engineering Department, Faculty of Engineering, The University of Nottingham, Nottingham, UK

ABSTRACT
There is a lack of a clear and consistent definition of human-centricity in Industry 5.0. This study identified the definition of human-centricity in Industry 5.0 through a systematic literature review and used it to assess the readiness of Ergonomics/Human Factors communities in the UK. The assessment of the communities readiness was conducted by reviewing UK accredited courses and events of three professional bodies; and interviewing practitioners (n = 8). Eleven themes were identified as elements of human-centricity from the thematic analysis of 30 publications. Gaps that had to be addressed to better equip UK practitioners to support the realisation of human-centricity in Industry 5.0 were also identified.

PRACTITIONER SUMMARY
The meaning of human-centricity in Industry 5.0 and its bearing on Ergonomics/Human Factors communities are not fully understood. Eleven themes that define human-centricity in Industry 5.0 are extracted. Gaps that have to be addressed by Ergonomics/Human Factors communities in UK are also identified.

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KEYWORDS
Industry 5.0; human-centricity; ergonomics; human factors

1. Introduction

The seamless integration of the physical and digital realms within the manufacturing domain is said to presage the coming of a fourth industrial revolution, or Industry 4.0 (Schwab 2017). This integration is facilitated by utilising advanced technologies such as cloud computing, big data analytics, artificial intelligence, and the Internet of Things (IoT). These tools and technologies are strategically layered across various levels of operation, collectively culminating in the transformation of manufacturing, logistics, and product offerings into intelligent and interconnected entities (Frank, Dalenogare, and Ayala 2019). Industry 4.0 holds the potential to deliver substantial advantages to the manufacturing sector, encompassing better product quality, decreased operational costs, heightened operational adaptability, elevated levels of customer satisfaction, and an enhanced competitive edge in the market (Wichmann, Eisenbart, and Gericke 2019; Zhang et al. 2021; Teixeira and Tavares-Lehmann 2023). Nevertheless, as technology continues to advance and become increasingly intricate, the adoption of Industry 4.0 also introduces a set of formidable challenges and associated risks. These challenges encompass cybersecurity threats, skills gaps, regulatory complexities, and organisational change (Veile et al. 2020; Abdul-Hamid et al. 2020).

One underlying issue that has surfaced is a perceived overemphasis on technology, with inadequate consideration of the human element within this evolving framework (Piccarozzi, Aquilani, and Gatti 2018; Neumann et al. 2021). Consequently, there emerges an imperative to reimagine the role of humans in the manufacturing sector, alongside an exploration of ways in which humans and machines can coexist harmoniously and efficiently (Nguyen Ngoc, Lasa, and Iriarte 2022). This lays the foundation for the essence of Industry 5.0, mooted as a corrective paradigm that aspires to establish an industry that is sustainable, human-centric, and resilient (Alves, Lima, and Gaspar 2023). It represents a departure from the preceding focus on technology-driven advancements to a more holistic vision, acknowledging the socio-technical

CONTACT Setia Hermawati setia.hermawati@nottingham.ac.uk Human Factors Research Group, Mechanical, Materials and Manufacturing Engineering Department, Faculty of Engineering, The University of Nottingham, Nottingham, UK.

system that permeates the modern workplace. Industry 5.0 is rooted in the idealogy of Industry 4.0 but shifts the focus from the techno-economic vision to human-centricity (Möller, Vakilzadian, and Haas 2022). While several studies have advocated the importance of human-centricity and proposed frameworks to implement it, there is still a lack of a clear and consistent definition of what human-centricity entails (Alves, Lima, and Gaspar 2023). For example, Breque, De Nul, and Petridis (2021) envision a future where technology is customised to suit the needs of workers, rather than requiring workers to adapt to technology. In this vision, advanced technologies such as virtual/augmented reality (VR/AR) are used to foster a social and collaborative workplace, where robots, mobile robotic systems, and exoskeletons reduce the physical demands of tasks, and artificial intelligence (AI) and virtual/augmented reality (VR/AR) tools provide guidance and support for workers in specialised tasks. This envisioned arrangement transforms workers from mere labourers into strategic assets for the organisation, aligning Industry 5.0 with a strong commitment to human-centricity and enhanced workplace well-being. Another conceptualisation of human-centricity within the framework of Industry 5.0 is proposed by Østergaard (2018), who suggests revisiting the manufacturing floor, drawing inspiration from pre-industrial eras, where humans hold a central role in the workplace. However, this time, their efforts are complemented by advanced technologies such as cobots, which are robots that are designed to work alongside humans in a shared workspace. The core principle of this approach is to reintroduce the human element into the world of mass production, by infusing human creativity into the landscape of digital manufacturing (Elfar et al. 2021). This harmonious blend of machine-human cognition serves as the linchpin for achieving the ambitious goal of hyper-customisation tailored to individual customer needs and services, as per Maddikunta et al. (2022). These conceptualisations illustrate the diverse and dynamic nature of human-centricity in Industry 5.0, as well as the potential benefits and challenges of implementing it in practice. However, despite its importance, there is a lack of critical attention to systematically define and clarify the concept and its semantic meanings, which can result in confusion and ambiguity about its usage and adoption. To the best of our knowledge, no prior work has analysed the meaning of human-centricity within the context of Industry 5.0. Therefore, the first aim of this research is to develop a coherent and unambiguous definition of human-centricity that applies to real-world problems and answer the Research Question 1 (RQ1) - the definition of human-centricity in industry 5.0 within the manufacturing context.

Given the potential for diverse and dynamic forms of human-centricity in Industry 5.0, there is a noticeable gap in the literature regarding the readiness of Ergonomics/Human Factors (E/HF) professionals to actively support and facilitate the realisation of human-centricity within the Industry 5.0 landscape. The International Ergonomics Association (IEA, 2000) defined E/HF as 'the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimise human well-being and overall system performance'. Accordingly, the E/HF discipline advocates a comprehensive, human-centred approach to systems design that considers the organisational, developmental, ecological, and environmental aspects as well as other factors important for the socio-economic growth and well-being of the global society (Kroemer, 2017). Some studies have highlighted the challenges faced by E/HF professionals in the context of implementing Industry 4.0, as observed by Hermawati and Lawson (2019). However, there have been alternative perspectives that have departed from the human-centric approach, positioning technology as the central focal point – these alternative approaches may inadvertently emphasise the management of these technologies as the primary task within the workplace (Reiman et al. 2021; Cunha, Silva, and Maggioli 2022; Silva et al. 2020). Considering the definition of human-centricity in Industry 5.0 outlined within this research, our study also aims to assess whether the E/HF community is adequately prepared to serve as facilitators in the adoption of Industry 5.0 principles within the manufacturing sectors and answer our Research Question 2 (RQ2) - Assessing the readiness of the E/HF community for the implementation of 5.0. This assessment extends to interviews with Human Factors practitioners and an examination of the alignment between the educational curricula and professional bodies within the realm of E/HF and the defined parameters of human-centricity in Industry 5.0.

2. Methodology

We implemented a two-stage methodology that first establishes the nature of Human-Centricity in a putative Industry 5.0 paradigm and then compares this with an analysis of the readiness of the Human Factors discipline to respond (see Figure 1 for a diagram of

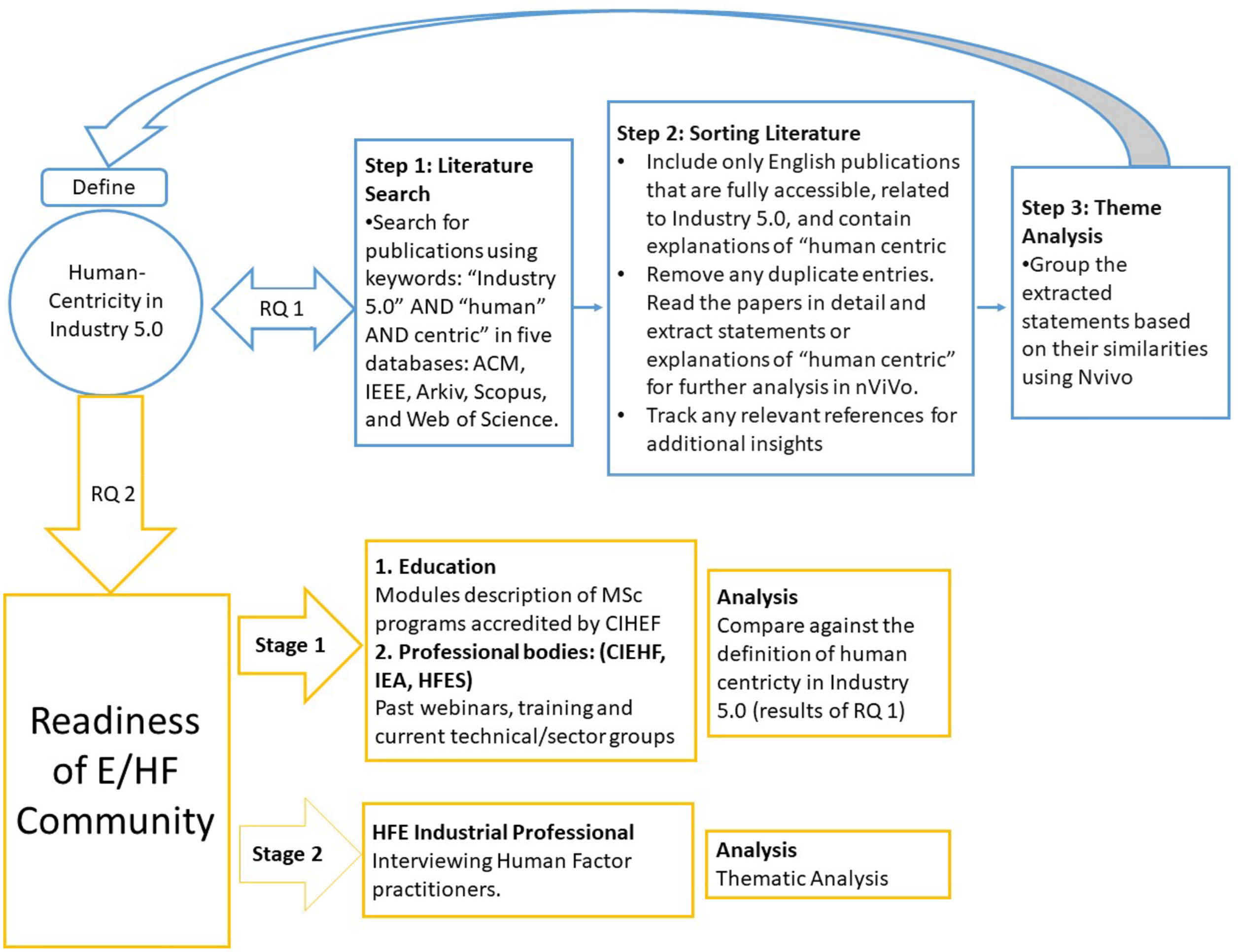

Figure 1. A flowchart of the research process for defining the human-centricity and assessing the readiness of the E/HF community for Industry 5.0.

the overall methodology). The following subsections describe the detailed of each stage.

2.1. A systematic review to define human-centricity in Industry 5.0

A comprehensive literature search and analysis was conducted on the concept of human-centricity within the context of Industry 5.0. The literature search followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Moher et al. 2009). The literature search was performed on 27 April 2023. Five reputable databases: ACM, IEEE, Arkiv, Scopus, and Web of Science (WoS), were searched using combined three keywords: 'Industry 5.0' AND 'Human' AND 'Centric'. Only publications that were in English and fully accessible were included in the first initial screening of the systematic review. We excluded Google Scholar in our literature search. While Google Scholar coverage is wide-ranging and comprehensive, the search engine does not make its criteria clear on what makes its search results 'scholarly' (Giustini and Boulos 2013). Furthermore, Google Scholar's search results often vary in quality, include non-peer-reviewed material, and are irreproducible (Gusenbauer and Haddaway 2020). An initial review based on the title and abstract of the papers was conducted to remove irrelevant entries. Only papers in the manufacturing sector and exploring human aspects of Industry 5.0 were included. The final sift was then performed by reading each paper in full to ensure that only paper containing a clear statement and description of human-centricity were included. Any duplicate papers were removed. Additionally, relevant references from the reviewed literature were traced and the same screening approach was applied. The literature selection process was completed by one researcher (SH).

Figure 2 shows the outcome of the literature selection process at different steps. A total of 30 publications were included to define the meaning of human-centricity in Industry 5.0. 70%, 23% and 7% of

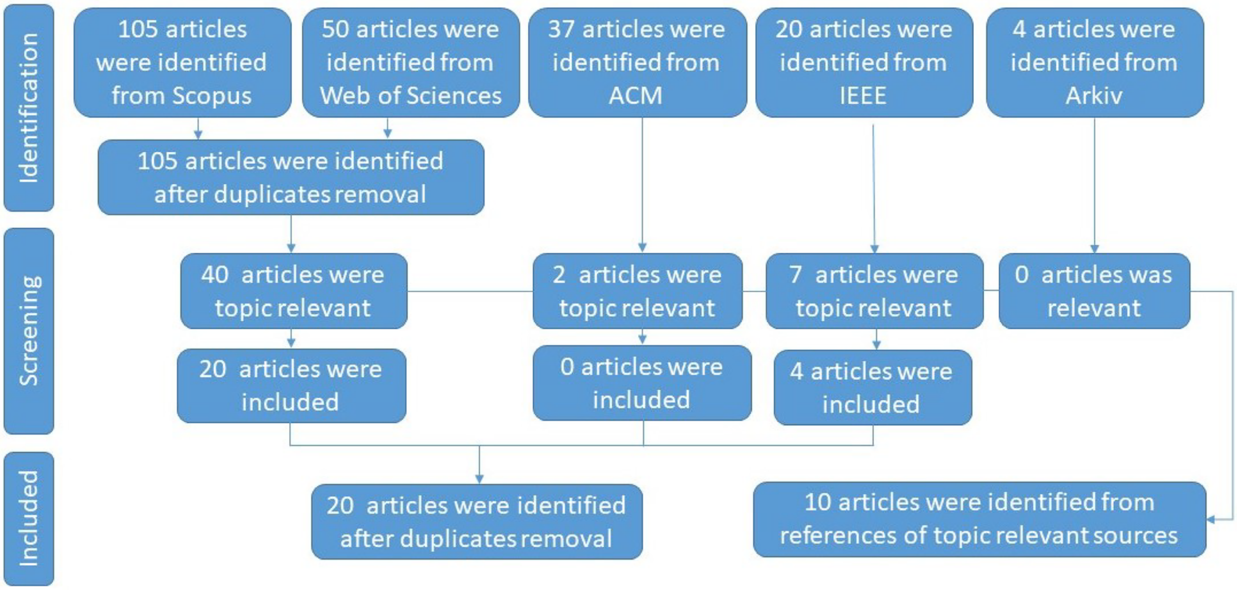

Figure 2. Outcomes of literature selection.

these publications were in the form of journal articles, conference papers, and technical reports, respectively. Out of the 21 journal articles, 70% of them was published in traditional journals and the remaining was published in journals that only accepted open-access articles. Appendix 1 provides a summary of publications that were included in the study to identify the definition of human-centricity and answer RQ1.

The next step of the systematic review was to identify statements on what constitutes human-centricity in Industry 5.0 in the manufacturing sector from each paper. Any statements, descriptions, and explanations related to human-centricity found in these additional sources were then extracted and catalogued in an Nvivo database. One researcher (SH) extracted and identified the statements from all papers. To validate the statements extracted by SH, a subset of papers were randomly sampled, and another researcher (GL) extracted statements from these papers independently. Following the recommendation of O'Connor and Joffe (2020), three papers (10% of the total number of the selected papers) were used for this validation process. The extracted statements from the two researchers (SH and GL) were then compared quantitatively and qualitatively across these three papers. Cohen's κ was run to determine if there was agreement between the two researchers. There was moderate to good agreement between the researchers, $\kappa = .54$. The essence of extracted statements from the two researchers were also compared quantitatively to check if the extracted statements from the second researcher were covered by SH's extracted statements. Both qualitative and quantitative comparison results showed that extracted statements were valid and acceptable for further analysis. Finally, a thematic analysis from these extracted statements was conducted. Two researchers (SH and RC) discussed the categorisation/grouping of the statements and themes identification. Any disagreements that occurred between the two researchers were resolved by discussing together to reach a consensus. The extracted statements were systematically categorised and grouped, enabling the derivation of a comprehensive and nuanced definition of human-centricity in Industry 5.0 within the manufacturing sector, as presented in the literature.

2.2. Assessment of E/HF community readiness

Building upon the definition of human-centricity in Industry 5.0 derived from the systematic literature review, this stage of research explored the readiness of the E/HF community (educational institutions, professional bodies, and practising Human Factors practitioners) to enable realisation of human-centricity in Industry 5.0 principles. A multi-phased approach was adopted. The first phase involved scrutinising the curricula of Human Factors courses offered by educational institutions in the United Kingdom that are accredited by the Chartered Institute of Ergonomics and Human Factors (CIEHF). Courses specialised in healthcare were excluded to maintain the context relevance. The descriptions of modules within these selected courses were analysed against the outcome of the systematic review to gauge alignment with the human-centricity themes derived in RQ1; thereby assessing how well future Human Factors professionals could address the need for human-centricity in Industry 5.0. On the other hand, activities offered by professional bodies such as CIEHF, the International Ergonomics Association (IEA), and the Human Factors and Ergonomics Society (E/HFS) were also compiled and compared against the human-centricity principles of Industry 5.0. Activities that were compiled from each professional body included webinars and training courses that were offered within the two years spanning 2021–2023 and technical groups. The comparison between the professional bodies and the human-centricity principles of Industry 5.0 was aimed to gauge the extent to which these bodies are actively guiding the E/HF community towards meeting human-centricity in Industry 5.0.

The second phase encompassed interviews with E/HF industrial practitioners across the discipline. Employing a semi-structured format, the interview questions were designed to explore core themes of human-centricity, establish a link between participants' prior knowledge and the formal terminology and definitions of these concepts and address both practical and theoretical aspects of human-centricity. The questions were divided into four areas: 1) demographics, 2) initial perceptions of Industry 4.0 and 5.0, 3) challenges and importance of human-centricity in Industry 5.0, 4) HF in Industry 5.0, and 5) reflection on the HF profession. Detailed of the interview questions were shown in Appendix 3. A convenience sampling strategy was used to recruit participants. Researchers' existing contacts of HF professionals on LinkedIn were approached and invited to participate. Invitation to participate were also sent to relevant LinkedIn networks of these contacts. The interviews typically lasted between 20 and 45 minutes and were conducted in August 2023. All interviews were recorded and transcribed verbatim to preserve the participants' perspectives and expressions, ensuring the accuracy and reliability of the data. The data was analysed using thematic analysis, which helped to identify key patterns and conclusions from the rich and intricate data. The interviews were approved by the University of Nottingham Faculty of Engineering Ethics Committee.

3. Results

3.1. Definition of human-centricity in Industry 5.0

This section outlines the results of thematic analysis to define human-centricity in Industry 5.0 based on the systematic search described in the previous section. Figure 3 presents the outcomes of the thematic analysis results of relevant statements that were extracted from publications, shown in detailed in Appendix 2. Figure 3 provides an overview of the 11 theme and their short summaries. The description for each theme is given below.

1. Guaranteeing physical and mental well-being in the workplace
   Employers must guarantee the wellbeing of employees, both physically and mentally (Ace-Factories, 2019; Breque, De Nul, and Petridis 2021; Xu et al. 2021; Yang et al. 2022; Kalateh et al. 2022; Carayannis, Canestrino, and Magliocca 2024). A workplace should provide a safe and stimulating environment for workers to perform their tasks (Nahavandi 2019; Grabowska, Saniuk, and Gajdzik 2022). A workplace should also aim to foster a positive and supportive culture that encourages job satisfaction, work engagement, workers empowerment and professional growth (Cluster, 2019; Breque, De Nul, and Petridis 2021; Turner and Garn 2022; Brunetti, Gena, and Vernero 2022). Additionally, a workplace should support workers to achieve their personal and professional goals and to balance their work and personal lives (Kalateh et al. 2022).
2. Meeting social, autonomy and ethical considerations
   It is important that workers have control over their work and data and that they are treated with respect and dignity (Breque, De Nul, and Petridis 2021; Ghobakhloo et al. 2022b). Furthermore, a workplace should also safeguard the privacy of workers and their personal information (Adel 2022) and follow ethical principles and standards in the use of technologies and processes (Longo, Padovano, and Umbrello 2020).
3. Inclusive workplaces
   It is important for a workplace to respect and accommodate the individual differences and limitations of workers (Ace-factories, 2019; Breque, De Nul, and Petridis 2021). The workplace should not discriminate or exclude workers based on their characteristics or abilities and provide workers with the necessary support and resources to perform their tasks effectively (Brunetti, Gena, and Vernero 2022; Kalateh et al. 2022; Yang et al. 2022; Leng et al. 2022; Huang et al. 2022). Ultimately, a workplace should aim to create a sense of belonging and

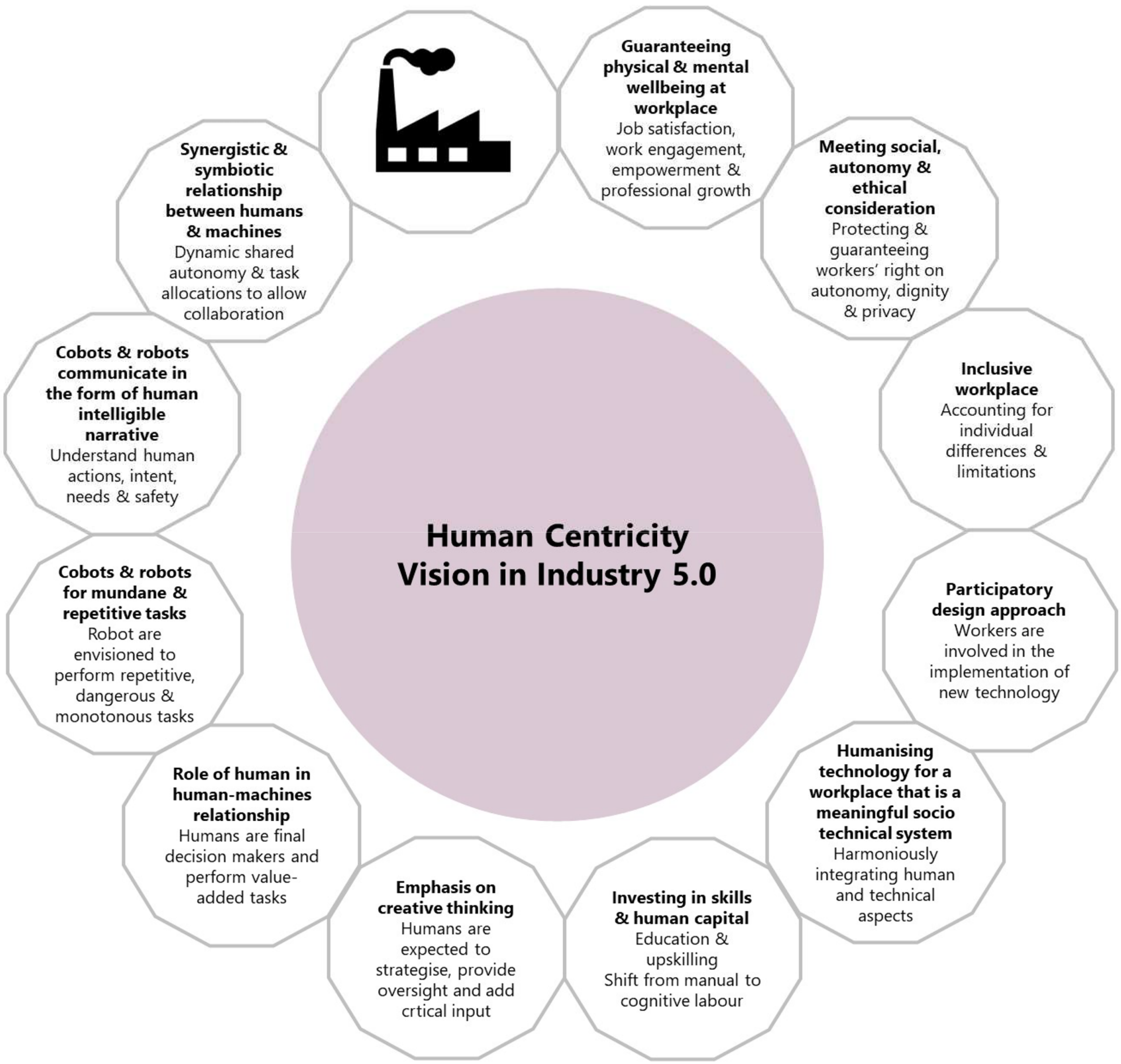

Figure 3. Aspects of human-centricity in Industry 5.0.

inclusion for all workers (Breque, De Nul, and Petridis 2021; Kalateh et al. 2022; Carayannis, Canestrino, and Magliocca 2024; Ivanov 2023).

4. Participatory design approach
Workers must be not just consulted in the development of new technologies but also be actively involved in their implementation (Breque, De Nul, and Petridis 2021; Atif 2023). This involvement will allow workers to test, evaluate, and improve the new technologies in their work context, and provide feedback and suggestions to the designers and developers (Brunetti, Gena, and Vernero 2022). As a result, the new technologies are more likely to meet the needs and expectations of the workers.

5. Humanising technology for a workplace that is a meaningful sociotechnical system
Creating a workplace that harmoniously integrates human and technical aspects is crucial (Longo, Padovano, and Umbrello 2020). It is important to view workers as vital investments in a workplace rather than as costs or liabilities (Breque, De Nul, and Petridis 2021; Madsen and Berg 2021; Grabowska, Saniuk, and Gajdzik 2022). A workplace should aim to put humans at the centre its production system (Brunetti, Gena, and Vernero 2022; Leng et al. 2022; Maddikunta et al. 2022; Carayannis, Canestrino, and Magliocca 2024; Möller, Vakilzadian, and Haas 2022). Moreover, it is essential to design

and/or redesign technology that adapts and better reflects human values, skills and physical and mental needs, without requiring workers to continuously update or have specific skills or training (Breque, De Nul, and Petridis 2021; Kalateh et al. 2022; Mourtzis, Angelopoulos, and Panopoulos 2022; Turner and Garn 2022).

6. Investing in skills and human capital
Employers also need to invest in the education and up-skilling of workers (Breque, De Nul, and Petridis 2021; Ghobakhloo et al. 2022b). The workplace should provide workers with opportunities to learn new skills and knowledge and to adapt to the changing demands of the workplace (Yang et al. 2022; Borchardt et al. 2022). The workplace should also support workers to shift from manual to cognitive labour (Longo, Padovano, and Umbrello 2020).
7. Emphasis on creative thinking
A greater role is identified in the future workplace for critical thinking skills (Demir and Cicibas 2017; Nahavandi 2019) and the ability to generate new ideas and solutions using their expertise (Maddikunta et al. 2022; Yang et al. 2022; Rožanec et al. 2022). Humans should provide strategy, monitoring, and creative input to the workplace (Mourtzis, Angelopoulos, and Panopoulos 2022; Yao et al. 2022).
8. Role of humans in the human-machine relationship
Humans should have final authority and accountability regarding the decisions and outcomes of the machines, particularly when those decisions have moral, legal, or ethical implications (Kalateh et al. 2022). As stated in theme 7, it is also recommended that humans carry out value-added work involving critical thinking, creativity, and judgement (Longo, Padovano, and Umbrello 2020; Maddikunta et al. 2022). Adopting this approach ensures that humans are not competing with robots (Ghobakhloo et al. 2022a; Yao et al. 2022), resulting in more jobs creation (Nahavandi 2019; Huang et al. 2022) and better roles for human in the production floor (Demir and Cicibas 2017).
9. Cobots and robots for mundane and repetitive tasks
This theme emphasises the need for using cobots and robots to perform tasks that are repetitive, dangerous, routine, or monotonous (Chaudhari et al. 2021; Maddikunta et al. 2022; Mourtzis, Angelopoulos, and Panopoulos 2022; Rožanec et al. 2022; Kalateh et al. 2022); and thus, allowing humans to focus on creative, complex, and meaningful tasks (Adel 2022). The use of these machines should also provide an opportunity to expand the capabilities of workers and make tasks less physically demanding and safer for the human (Breque, De Nul, and Petridis 2021; Maddikunta et al. 2022).
10. Cobots and robots communicate in the form of human-intelligible narrative
In a future workplace, cobots, robots and other automated systems will need to communicate with humans naturally and understandably (Mourtzis, Angelopoulos, and Panopoulos 2022). They can analyse human intent, desire, needs and safety, and act accordingly (Kalateh et al. 2022; Leng et al. 2022; Maddikunta et al. 2022; Lu et al. 2022). They can also understand human actions and future movements and anticipate their needs (Nahavandi 2019; Turner and Garn 2022).
11. Synergistic and symbiotic relationship between humans and machines
Ultimately humans and machines should have a synergistic and symbiotic relationship (Nahavandi 2019; Leng et al. 2022; Grabowska, Saniuk, and Gajdzik 2022; Kalateh et al. 2022; Bajic et al. 2023; Ivanov 2023) in ways that benefits workers (Longo, Padovano, and Umbrello 2020) and increases process efficiency (Ghobakhloo et al. 2022a). This can be achieved through dynamic change of dependence between humans and machines depending on the situation and the task (Romero and Stahre 2021; Lu et al. 2022). Humanised design of machines will allow humans and machines to co-work, collaborate, and combine their strengths (Mourtzis, Angelopoulos, and Panopoulos 2022; Maddikunta et al. 2022; Yang et al. 2022;) rather than removing humans from production roles (Rožanec et al. 2022; Turner and Garn 2022; Brunetti, Gena, and Vernero 2022).

3.2. Assessment of E/HF accredited courses and professional bodies

Four courses in UK that were relevant to this research context and accredited by the CIEHF were identified. Commonalities in the modules were observed between these courses, especially for foundation modules such as Physical, Cognitive and System Ergonomics, research skills modules, and research project modules. Beyond these common modules, each course offered modules that contributed towards specialisation in E/HF. Table 1 shows a summary of compulsory and optional modules offered in each course. For simplification, modules related to research skills and research projects were excluded from the list. The review of accredited degree courses is obviously limited in that the detailed content of each class, and e.g. assignment topics, is not presented on the university websites. Nonetheless the review serves as an indicator of the emphasis i5.0 human-centricity concepts receives within the accredited courses.

Activities from professional bodies (webinars as well as technical sectors/groups and training courses in the last two years) were also compiled. Table 2 shows a summary of these activities. Although the technical/sector groups in CIEHF were significantly smaller than HFES and IEA, they complemented each other, and all covered a wide range of topics. Each professional body also appeared to put different emphases on their webinar's activities. CIEHF webinars were dominated with health care and defence related topics, whereas IEA and HFES webinars focused, respectively, on future of work/musculoskeletal disorders and sustainability/diversity. Only the CIEHF offered direct training.

Table 3 shows the comparisons between the accredited E/HF courses and professional bodies' activities against the proposed definition or vision of human-centricity in Industry 5.0. They show that there

Table 1. List of UK universities offering degree courses accredited by CIEHF.

No.	University	Degree course	Relevant modules
1.	Loughborough University	MSc, PGDip, PGCert, in Ergonomics and Human Factors	Cognitive Ergonomics, Physical Ergonomics, Occupational Ergonomics, Interaction and Experience Design, Human Factors and Systems, Environmental Ergonomics, Inclusive Design for Products and Services, Transport Safety, Healthcare Ergonomics and Patient Safety, Patient Handling
2.	University of Nottingham	MSc. in Human Factors and Ergonomics	Physical Ergonomics, Cognitive Ergonomics in Design, Studying Human Performance, Simulation, Virtual Reality and Advanced Human-Machine Interface, Work Systems and Safety, Human-Computer Systems, Advanced Methods in Human Factors and Human-Computer Interaction, Medical Device Design and Regulation, Biomechanical Analysis of Human Motion, Advanced Methods in Psychology
3.	University of Derby	MSc. in Fundamentals of Ergonomics and Human Factors	Fundamentals of Ergonomics and Human Factors, Cognitive Ergonomics and Psychology, Physical Ergonomics, Systems Ergonomics, Contemporary Issues in Ergonomics and Human Factors, Ergonomics and Human Factors (Behaviour Change)
4.	Cranfield University	MSc. Safety and Human Factors in Aviation	Cognitive Ergonomics, Human Error and System Safety, Human-Computer Interaction in Aviation, Safety Assessment of Aircraft Systems, Applied Safety Assessment, Aviation Safety Management, Aircraft Accident Investigation and Response, Safety and Human Factors in Aviation Course Induction, Flight Data Monitoring, Training and Simulation, Human Factors in Aviation Maintenance.

Table 2. Summary of activities organised by professional bodies between 2021 and 2023.

Activities type	Professional body	Number	Details
Webinars	CIEHF	24	Health care (4x), Defense (3x), Accident and safety (2x), system design (2x), Robotic & automation (2x), Usability, Equality, Diversity and Inclusion, Working from home, Ergonomics Standards, Work design, HF in pharma manufacturing, HF in oil & gas, Climate change, Cyber security, Organisational change, Exoskeleton
	IEA	29	Future of work (10x), Musculoskeletal Disorders (5x), Healthcare (3x), Artificial Intelligence (2x), Human-robot interaction (3x), E/HF in manufacturing (2x), Socio technical system (2x), Training, Working from home, Smartphone use
	HFES	19	Sustainability (8x), Equality, Diversity and Inclusion (3x), Product design (2x), Musculoskeletal Disorders, Data visualisation, Occupational ergonomics, Human-AI robot teaming, Education, Built environment.
Technical/sector groups	CIEHF	7	HF in workplace, healthcare, pharmaceutical, children's ergonomics, defence, nuclear and automotive
	IEA	26	Building & construction, digital human modelling and simulation, ergonomics work analysis and training, ergonomics for children and educational environment, ergonomics in design for all, ergonomics in manufacturing, gender & work, healthcare ergonomics, HF & sustainable development, HF in robotics, informal work, mining, musculoskeletal disorders, organisational design & management, resilience engineering, safety & health, transport ergonomics & HF, visual ergonomics, work with computing systems, slips, trips & fall.
	HFES	27	Aerospace system, ageing, augmented cognition, children's issues, cognitive engineering & decision making, communications, computer systems, cybersecurity, education, environmental design, extended reality, forensics, health care, human-AI robot teaming, human performance modelling, individual differences in performance, internet, macro ergonomics, occupational ergonomics, perception and performance, product design, safety, surface transportation, sustainability, system development, training and usability & system evaluation
Training Course	CIEHF	33	Training on general HF, DSE, healthcare, manufacturing, energy, rail, engineering.
	IEA	0	N/A
	HFES	0	N/A

Table 3. Gaps identified in E/HF degree courses and E/HF professional bodies based on human-centricity aspects in Industry 5.0.

No.	Aspects of human-centricity in Industry 5.0	Identified gaps: E/HF degree courses	Identified gaps: E/HF professional bodies
1	Guaranteeing physical and mental well-being at workplace	Aspects such as mental health, empowerment, and professional growth were not explicitly apparent from modules description across all courses.	There are noticeable gaps related to mental and psychological health as well as employees' engagement and empowerment. A holistic view encompassing psychological and motivational factors is also lacking.
2	Meeting social, autonomy and ethical consideration	Social and ethical considerations of workers were not explicitly apparent from the module description across all courses.	There is very limited focused on ethics, workers' rights and privacy considerations
3	Inclusive workplaces	While only one programme explicitly stated inclusive design, description of modules from other programmes clearly showed that this theme was more or less addressed in all courses.	Diversity and inclusion is touched on but not comprehensive and comprehensive instruction is lacking.
4	Participatory design approach	A course explicitly stated 'macroergonomics'. However, modules of similar approach, e.g. user-centred design, human-centred design, were also offered in other courses.	There is very limited focused on participatory design approach, although there is a dedicated technical group related to macro ergonomics.
5	Humanising technology for a workplace that is a meaningful sociotechnical system	This theme was addressed in all courses.	This theme is somewhat covered based on the range of technical groups HFES and IEA suggests that this theme is covered. However, there is a lack of coverage in webinars event.
6	Investing in skills and human capital	Reskilling and upskilling as well as cognitive labour shift were not explicitly apparent from modules description across all courses.	There is a clear lack of focus on skills and human capital aspects from professional bodies' activities. Only one technical group is relevant with this theme and no webinars or training covered this theme.
7	Emphasis on creative thinking	While some relevant cognitive systems modules existed, their application to oversight and creativity were not apparent.	There is a clear gap related to the importance of creative thinking from professional bodies' activities.
8	Role of humans in human and machine relationship	This theme was partially addressed in all courses. However, it was not clear how extensive the course covered the future implication of the changing roles of human.	This theme is somewhat covered based on the range of technical groups and webinars in HFES and IEA.
9	Cobots and robots for mundane and repetitive tasks	Cobots and robots were not explicitly stated in any of the programme. However similar terms were used in a course.	This theme is somewhat covered based on the range of technical groups in HFES and IEA.
10	Cobots and robots communicate in the form of human-intelligible narrative	Most courses covered this theme as part of general human-computer interaction or human-robot interaction topics. However, it was not clear if understanding of human-intent, desires, needs etc. were also included.	This theme is somewhat covered based on the range of technical groups in HFES and IEA.
11	Synergistic and symbiotic relationship between humans and machines	This theme was addressed in all courses.	This theme is somewhat covered based on the range of technical groups and webinars in HFES and IEA.

are gaps in the current education of future Human Factors professional and professional bodies in the context of human-centricity in Industry 5.0 in UK. While existing modules equipped Human Factors professional with the foundation of E/HF principles, there seems to be limited exposure to real-world applications of the latest technology (e.g. cobots, robots, AI) and future work-related issues (e.g. ethics and social issues at work, the needs for upskilling and reskilling, importance of creativity in human-machine collaboration). This will likely result in less than optimum ability of these future professional to anticipate and mitigate negative consequences when facing these issues. Therefore, a regular review on the content of curriculum would likely be beneficial. With regard to professional bodies, at least for IEA and HFES, the gaps between the two were somewhat lesser because of the presence of technical groups which are more or less driven by changes in workplaces, industry and technology. However, this observation does not apply to CIEHF (UK), as the range of technical groups were narrow and tend to be industry specific. CIHEF is the only professional body that provides training courses covering various E/HF issues. However, on closer look, these training courses are limited to foundation E/HF principles and do not cover the latest developments related to workplace, industry and technology. Therefore, similar to the state of current education of future Human Factors professionals in UK, there is also a substantial gap between CIEHF's activities and the definition of human-centricity in Industry 5.0. Failure to close the gaps between the current education and professional body activities mean that the recent momentum towards human-centricity in the Industry 5.0 framework is not realised fully; and as a result a possible continuation of the current circumstance in which technology is at the forefront and centre of workplace.

3.3. Human-centricity in Industry 5.0 among E/HF professionals

Semi-structured interviews were conducted with eight E/HF professionals to extract their current understanding of human-centricity and readiness for Industry 5.0, according to the method presented in Section 2.2. Table 4 provides the demographic summary of these professionals.

The interview results showed that participants have limited knowledge of Industry 4.0 and 5.0, with 6 out of 8 participants having either never heard of it or heard of it but with no understanding on what they meant. There is the possibility that this was because the E/HF professionals that were involved in the study did not have much exposure to Industry 4.0 and 5.0 in their work as exemplified by one of participants' statement: 'I am not familiar with the term Industry 5.0. It is not something I have come across in my work'. However, nearly all E/HF professionals (n = 7) had heard of human-centricity terminology and linked it from the human-centred design concept in E/HF.

Drawing from their professional experiences, participants identified several challenges in achieving human-centricity in Industry 5.0. The first challenge was related to the need to provide or demonstrate the evidence of benefits that are associated with adopting human-centricity. Several participants mentioned that quantitative and financial-based evidence were always required to convince relevant stakeholders to adopt a proposed solution or approach and that failure to do so would result in the inability to secure the necessary resources to implement the proposed solution. Another challenge reported was the difficulties in collaborating and synchronising differing priorities in a multidisciplinary project. For instance, one participant explained that it was difficult to make engineers they worked with look beyond technical aspects and adopt a holistic view akin to systems thinking. Another challenge identified by participants was a common view, commonly adopted outside E/HF communities, that the human is a weak link in a workplace and thus needs to be replaced with a more reliable tool such as AI-based technology. However, the constant addition of the latest technology puts a further demand on human workers and as identified by one participant, this type of technology was rarely capable in handling unexpected situations and is less flexible or adaptable in comparison to human workers. The final challenge identified by the participants were the lag in regulation in keeping up with the technology advancements. For instance, they were unaware of any regulation related to cobots and the use of AI alongside human workers in workplace. Despite these challenges, all participants agreed on the importance of human-centricity and the 11 themes that were identified from the literature reviews were all deemed relevant and important.

Depending on their professional experiences, participants' views on the potential E/HF contribution in accommodating human-centricity in Industry 5.0 were quite varied. However, all participants agreed that the main HF contribution is related to ensuring that human limitations and capacities are accounted for in workplaces. Two participants stated that HF has also contributed to raising the awareness of the importance of acknowledging human limitations and capacities and adopting system thinking for stakeholders who are outside of E/HF communities. Participants agreed that E/HF as a field is not fully ready to address human-centricity aspects of Industry 5.0. Some participants identified several gaps or opportunities that needed to be addressed by E/HF communities, for example, providing guidance on human-centric technology development beyond tech-centric approaches which support the implementation or operation of the technology. Some participants identified the need to engage closely with organisation leaders so that E/HF communities could provide strategic guidance across project lifecycles and not just within a specific part of the lifecycle. Moreover, E/HF communities should push forward system thinking when they collaborate with experts in other fields.

Nearly all participants agreed that communication skills are paramount as an E/HF professional and would

Table 4. Demographics of participants.

No	Years in E/HF	Primary sector	Education	Other information
1	10	Oil	PhD in Human Factors	Also works in consultancy
2	1	Energy	MSc in Human Factors	Background in engineering
3	2	Energy	MSc in Human Factors	Background in engineering
4	25	Rail	MSc in Ergonomics	Leadership role, extensive rail experience
5	9	Automotive, Aerospace, Rail, Healthcare	PhD in Human Factors	Background in engineering and computer science
6	1	Energy	MSc in Human Factors	–
7	24	Automotive		Currently Ergonomics Manager
8	30+	Aerospace, Rail, Oil/Gas, Healthcare	PhD in Human Factors	Works in consultancy and academic research

be a great asset to have to support the adoption of human-centricity in Industry 5.0. These skills were required when an E/HF professional interacted and engaged with end users and relevant stakeholders to gain and understand their perspectives; and obtained buy-in from relevant stakeholders. Another generic skill that was deemed to be useful to support realising human-centricity in Industry 5.0 was pragmatism, especially in a circumstance where an ideal solution to a problem is not feasible to be implemented and a trade-off or compromise was required. Additionally, some participants, depending on their professional experience, referred to specific E/HF techniques as skills that were required from E/HF professionals e.g. task analysis, system thinking. All participants mentioned that they spent effort to stay up to date, albeit within their field of practice. This observation was common among participants. It was also revealed that participants rarely attended E/HF conference even though most participants expressed their willingness to attend research conferences provided their attendance was covered by their workplace or organisation. All participants stated that they were often worked in a collaboration in their projects even if the collaboration was limited to within their internal organisation or workplace.

4. Discussion

4.1. Potential contribution of E/HF in human-centricity

Human-centricity in Industry 5.0 is a socio-technical revolution that prioritises the well-being of humans in manufacturing systems. The primary aim of human-centricity in Industry 5.0 is to create a safe, inclusive, and respectful workplace environment for all employees. This means prioritising the physical and mental health of workers, respecting the diversity and dignity of humans, involving workers in the design and implementation of technology, and considering their feedback and preferences (Alves, Lima, and Gaspar 2023). Human factors professionals can help by designing machines and workspaces that fit the needs and abilities of the workers and ensuring that the human-machine interaction is intuitive, transparent, and supportive. The next goal of human-centricity in Industry 5.0 is to utilise the unique skills of humans such as emotional intelligence, compassion and creativity for sustainable growth in business areas. Machines can assist with tedious and dangerous tasks while humans use their skills, motivation and creativity in more meaningful ways, improving the overall system performance (Ericsson 2023). Human factors professionals can help by identifying the optimal division of labour between humans and machines and designing systems that enhance human capabilities and potential. Human-centricity in Industry 5.0 promotes collaboration between humans and robots or cobots, treating them as colleagues and communicating with them with trust. This means that humans and machines work together as a team, sharing information, goals, and feedback, and adapting to each other's behaviour and situation (Firescu et al. 2022 & Alojaiman 2023). Human factors professionals can help by designing robots and cobots that can communicate and cooperate with humans effectively and establishing new social and ethical guidelines to safeguard the privacy and dignity of both. Similarly, any AI-based technology should be designed responsibly, considered human well-being, respected privacy and human cognitive capacities while following human-centered design principles and complying appropriate governance (Garibay et al. 2023). Finally, Industry 5.0 invests in humans to improve their competence, behaviour, and creative efficiency. This means supporting and empowering humans with technological changes rather than leaving them behind. Humans need to learn new skills and adapt to new situations, and they need to be motivated and satisfied in their work (Pacher, Woschank, and Zunk 2023). Human factors professionals can help by providing training, mentorship, and continuous learning opportunities for workers, and designing systems that provide feedback, guidance, and recognition. In summary, human-centricity in Industry 5.0 recognises the value of humans in the workplace and creates an environment that supports their well-being and growth. Human factors professionals play a vital role in achieving this goal by designing machines, workspaces, and policies that fit the needs and abilities of humans and ensuring their well-being and satisfaction.

4.2. Readiness of E/HF curricula and professional

The comparison of the E/HF curricula and the guiding principles of professional bodies revealed both alignment and divergence in preparing the E/HF discipline for the human-centric vision of Industry 5.0. The analysis indicated that both the curricula and the professional bodies recognised the importance of human-centricity in Industry 5.0, but there were significant gaps in addressing the social, ethical, and human-technology collaboration aspects. One of the main findings was the strong emphasis on physical safety and ergonomics in both the curricula and the professional guidelines, which reflects the historical roots of the E/HF discipline and the need for standardisation (Prasetyo 2020). However, some universities lacked courses on sociotechnical systems and E/HF issues that were associated with emerging technologies. To achieve a human-centric Industry 5.0, it is essential to prioritise the psychosocial well-being, ethics, and collaboration of humans and machines, as well as the human values, society, and benefits that E/HF and industry can jointly promote (Moktadir et al. 2018). This discrepancy suggests a potential oversight of the current education and training of E/HF specialists. The professional body CIEHF has specific standards and hours that the curricula must adhere to, and it would be beneficial if they were updated and revised to reflect the changing needs of the E/HF discipline (CIEHF, n.d.). The examination of the events organised by the professional bodies showed that they currently do not offer a comprehensive programme to help prepare E/HF professionals for the challenges and opportunities of Industry 5.0. Moreover, the events offered tend to focus on traditional topics related to E/HF, while neglecting the topics on holistic well-being and worker well-being, which are crucial for a human-centric Industry 5.0. These findings were particularly pertinent in the UK's CIEHF; greater evidence of technical/sector groups and other activities related to upcoming technological advancements was demonstrated from the IEA and HFES websites. Furthermore, the professionals will need to be more proactive and flexible in adapting to the changing technologies and may require more frequent and continuous learning, which may increase their financial and time burden.

The interview with the professionals revealed a limited understanding of the emerging paradigms of i5.0 within the E/HF discipline, indicating the need to broaden the exposure and awareness of the professionals. These findings are consistent with previous research, which suggested that companies were underutilising the benefits of technological advancement due to the lack of knowledge and skills in the E/HF field (Virmani and Salve 2021). Several participants expressed that they were unfamiliar with the concept of human-centricity, which is a key element of Industry 5.0. This is in line with the literature reporting fragmented perspectives and a lack of a unified definition of human-centricity among E/HF scholars and practitioners, which hinders the development and implementation of human-centric solutions in the industry (Breque, De Nul, and Petridis 2021). A potential contributing factor to this phenomenon was probably the tendency of professionals to stay up-to-date only within their industry and low participation in E/HF conferences in which the latest research was often presented. The interview also identified critical skills that were required for a professional to thrive in the E/HF field, such as communication to enable working in an interdisciplinary project and engaging with various end users and stakeholders. However, these skills are not new; communication, empathy, and systems thinking are essential abilities for E/HF professionals to excel in the field (Rantanen and Moroney 2011). Another prominent theme that emerged from the interview was the perception of humans as the 'weak link' in the industry, which implies a need for more human-oriented and human-friendly technologies. As technology advances, the role of humans in the industry may shift to more cognitive-based work, as suggested by prior research (Fettermann et al. 2018). Taken together, these findings indicate that there is a gap between the current state and the desired state of E/HF readiness for Industry 5.0, and a lack of widespread acknowledgement and understanding of the concepts of Industry 5.0 and human-centricity among the E/HF professionals.

The results of the study have significant implications both for theory and practice. First, they provide an extensive overview of the current and desired state of E/HF readiness for Industry 5.0. The study also identifies the gaps and challenges that need to be addressed in this area. This information can help researchers, educators, and practitioners to understand current and future trends in industrial innovation. Additionally, it can help them to develop and implement effective strategies and solutions to enhance E/HF readiness. Second, the study highlights the crucial role that human factors professionals in achieving the human-centred vision of Industry 5.0. This vision requires a holistic approach that considers the well-being, empowerment, and growth of humans. Therefore, human factors professionals can design and evaluate human-machine systems and interactions that are collaborative, respectful, and beneficial for both parties. Third, the study emphasises the importance of human factors professionals acquiring new skills and capabilities essential for Industry 5.0. These skills include strategy, creativity, critical thinking, and advocacy. By developing these skills, they can enhance their professional development and career prospects. Moreover, it can help them to contribute to the advancement of human-centric technology.

4.3. Study limitations

This study had several limitations. Approximately a quarter of the publications that were used to define the definition of human-centricity in Industry 5.0 could be considered as 'grey literature'. In addition to technical reports (n=2), some of the journal articles were published in journals that only accepted open access articles (n=6). Although a peer review process was present in this type of journal, this process might not be as rigorous as traditional journals to allow rapid publication of academic articles, with an associated risk to the quality of the published science (Oviedo-García 2021). Another limitation of this study was the fact that the evaluation of the curricula for certified CIEHF courses and professional bodies was based only on publicly available information; therefore, there was a risk that the evaluation results did not provide a complete picture of the readiness of E/HF as communities in UK and beyond.

In hindsight a focus group study for E/HF professionals would have been a better method instead of a series of individual semi-structured interviews. A focus group would provide richer feedback so that E/HF professionals had more opportunities to express and exchange their thoughts collaboratively.

5. Conclusions

This study defined the human-centricity in Industry 5.0 through a systematic literature review. The definition of human-centricity in Industry 5.0 reveals that it extends beyond the conventional understanding of 'fitting the work/job/task to the human'. There are additional facets such as well-being, inclusivity, social and ethical consideration, and supporting adaptation to the changing demands of the workplace skills for workers. The proposed definition can assist current and future E/HF practitioner to promote, inspire and champion the implementation of human-centricity in Industry 5.0, potentially leading improvement in the overall well-being of current and future workers, and support the wide-reaching goals of United Nation's Sustainable Development Goals to increase equality and promote lifelong learning. However, translation of these definitions into tangible and practical actions will still need further studies/exploration and require a sustained collaboration across all stakeholder communities, including researchers, developers, business leaders, and policy makers.

This study also identified the gaps in the readiness of E/HF communities to address human needs in the context of Industry 5.0. The gaps revealed that current curricula on E/HF accredited courses and professional activities in the UK require some adjustments to better equip UK professionals in supporting the realisation of human-centricity in Industry 5.0. The identified gaps and the proposed definition of human centricity can be used as a starting point by relevant UK academic institutions and the CIEHF to reflect and take necessary actions to ensure that current and future E/HF professionals have the capability to enable human-centricity in Industry 5.0. As this study only used accessible information online for the identification of gaps, UK academic institutions and the CIHEF need to use more comprehensive information (e.g. detailed course syllabus for E/HF curricula, text analysis of discussion topics in member only forums) to obtain accurate assessment.

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The authors report there are no competing interests to declare.

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Appendix 1. Summary of the publications included in the study to define human centricity in industry 5.0

No.	Authors, Year	Summary
1.	Mourtzis, Angelopoulos, and Panopoulos (2022)	The paper discusses the transition from Industry 4.0, which focused on operational efficiency and new business models, to Society 5.0, which emphasises human-centric technologies and societal transformation. The authors provide a framework for this transition.
2.	Ghobakhloo et al. (2022a)	The paper explores how Industry 5.0 can foster sustainable industrial transformation. The authors review the literature and find 11 actions and approaches that enable Industry 5.0. The study highlights the importance of stakeholder integration, governmental support, eco-innovation, and value network reformation for Industry 5.0. The study also develops a strategy roadmap for enabling Industry 5.0 transformation and sustainable development.
3.	Atif (2023)	The study investigates the relationship between the circular economy (CE), Industry 4.0, and Industry 5.0. The author conducts a literature review and analyses material and information flow in smart manufacturing. As a result of placing humans at the core of production and focusing on the environment, the results reveal that I5.0 is more comprehensive, and value driven than I4.0 that complements CE.
4.	Bajic et al. (2023)	The author develops a model for data optimisation in edge computing for smart quality management, contributing to the human-centric approach of Industry 5.0. The proposed model uses edge computing to reduce data size and energy consumption, while preserving meaningful information. The model also considers the human factor in decision-making. The model is tested on manufacturing data and shows a high data reduction rate.
5.	Carayannis, Canestrino, and Magliocca (2024)	The study investigates how to transition from Industry 4.0, which has negative consequences due to its technocentric views, to Society 5.0, which emphasises a human-centric approach in which technology assists people and society. The article provides a framework based on the Quintuple Helix Model to guide how diverse actors and sectors might collaborate to achieve the aims of Society 5.0.
6.	Adel (2022)	The author discusses the potential applications, which emphasises human-machine collaboration and personalised products. The paper discusses how Industry 5.0 can be applied in different sectors and what technologies can support it. The paper also identifies the difficulties and issues of integrating robots and people in production.
7.	Rožanec et al. (2022)	The paper proposes a new architecture that combines artificial intelligence, simulated reality, decision-making, and user feedback for Industry 5.0. The architecture aims to enhance human-machine synergy, safety, trustworthiness, and human-centricity.
8.	Ghobakhloo et al. (2022b)	The paper proposes a strategy roadmap that explains how Industry 5.0 can contribute to sustainable development. The paper introduces the Industry 5.0 reference model and identifies 16 functions that deliver sustainability values. The paper uses interpretive structural modelling and expert opinions to construct the roadmap and explain the relationships among the functions.
9.	Huang et al. (2022)	This paper compares and complements Industry 5.0 and Society 5.0, two visions for human-centric and sustainable development in Europe and Japan. The paper also discusses how they can co-evolve and inspire future research.
10.	Borchardt et al. (2022)	The article delves into Industry 5.0, which seeks to address the limitations and constraints of Industry 4.0 by introducing business innovations for a more sustainable, human-cantered, and resilient industry. The paper examines the literature on Industry 5.0 from the perspectives of business and operations management.
11.	Grabowska, Saniuk, and Gajdzik (2022)	The author discusses the transition from Industry 4.0 to Industry 5.0, focusing on humanisation and sustainability. The paper uses bibliometric analysis to identify the trends and gaps in the literature on Industry 4.0 and Industry 5.0. Also, it highlights the importance of employee skill development in Industry 5.0.
12.	Nahavandi (2019)	The paper explores the concept of Industry 5.0, focusing on human-robot collaboration in the manufacturing industry. The paper discusses the features, concerns, developments, and impacts of Industry 5.0 on the economy and productivity. The paper claims that Industry 5.0 will create more jobs than it will eliminate.
13.	Turner and Garn (2022)	The paper discusses the future of Discrete Event Simulation (DES) in human-centric manufacturing systems, as well as a research agenda based on Industry 5.0 concepts. It proposes a research plan for the future generation of DES, which will integrate it with other technologies and approaches for capturing human behaviours and decisions.
14.	Lu et al. (2022)	This paper addresses the importance of having a solid understanding of human-centric manufacturing. It provides a reference model along with enabling technology for systems that prioritise worker well-being. The aim is to fulfil human needs ranging from safety to self-actualisation while also encouraging growing human-machine connections.
15.	Yang et al. (2022)	The paper explore how HMI can support Industry 5.0 and HCSM. The authors provide an HMI framework and reviews existing research on four aspects of HMI. The paper also predicts future challenges and opportunities of HMI for HCSM, which focuses on workers' well-being and sustainability.
16.	Brunetti, Gena, and Vernero (2022)	The paper surveys smart interactive technologies in Industry 5.0 and human-centric smart manufacturing. It reviews the state of the art, the benefits, the challenges, and the guidelines of using these technologies in a human-centric way. The paper categorises surveyed works by tasks and activities.
17.	Kalateh et al. (2022)	This paper focused on Industry 5.0 emphasising human-centeredness in manufacturing. The paper discusses the role, skills, and challenges of humans in Industry 5.0. It also delivers a roadmap for developing and using human-centric skills and technologies.
18.	Ivanov (2023)	The author proposes a framework for Industry 5.0 focusing on viability, which combines principles and technologies to create resilient, sustainable, and human-centric systems. The paper identifies the dimensions, principles, areas, and levels of Industry 5.0. It also defines Industry 5.0 and its value for profit, people, and society.
19.	Romero and Stahre (2021)	The author proposes the Resilient Operator 5.0, a concept that combines human and machine resilience in Industry 5.0. The paper envisions the future of work in smart resilient manufacturing systems and suggests how to use Operator 4.0 typology and solutions to achieve it.
20.	Longo, Padovano, and Umbrello (2020)	The paper explores how to design technologies for Industry 5.0 that reflect human values and ethics. The authors uses the Value Sensitive Design (VSD) approach as a framework and gives practical steps for engineers and designers for enabling human-machine symbiosis in the Factory of the Future.
21.	Demir and Cicibas (2017)	The paper compares Industry 4.0 and Industry 5.0, two paradigms for manufacturing. The paper criticises Industry 4.0 for its limitations and praises Industry 5.0 for its sustainability. The paper also argues that the next industrial revolution should be driven by information technology and environmental sustainability.
22.	Madsen and Berg (2021)	The authors analyse the literature on Industry 5.0, a new concept for future industries. The paper maps the field and provides a preliminary overview of its emergence and status. The paper also discusses the results in relation to theories on new management concepts and speculates on the future of Industry 5.0.

No.	Authors, Year	Summary
23.	Chaudhari et al. (2021)	This paper proposes an 'Enhanced version of Industry 5.0' that balances technology, human factors, inclusiveness, and ecology. The paper argues that Industry 5.0 and bioeconomy are opportunities, not threats. The paper also discusses the importance of bioeconomy for India and suggests policies for sustainable development.
24.	Yao et al. (2022)	The authors propose a socio-technically enhanced wisdom manufacturing, a concept that goes beyond Industry 4.0 and CPS. It addresses the roadmap to blockchainized value-added socio-cyber-physical system (SCPS) based Industrial Metaverse for Industry/Society 5.0. The paper aims to provide products and services that meet individual needs and promote smart, resilient, sustainable, and human-centric solutions.
25.	Cluster (2019)	The technical report by ACE Factories Cluster reviews five EU projects on human-centred factories. The report shares the experiences, methods, technologies, challenges, and solutions from these projects. The report also presents case studies from different sectors and gives recommendations for future work.
26.	Xu et al. (2021)	The paper compares Industry 4.0 and Industry 5.0, two concepts that have different origins, focuses, and implications. The paper discusses five questions about these paradigms from various perspectives, such as technology, economy, society, and environment. The paper also aims to stimulate further debate and discussion on these topics.
27.	Maddikunta et al. (2022)	The authors introduce several new concepts and definitions of Industry 5.0 from the perspective of different industry practitioners and researchers. The paper reviews the concepts, applications, and technologies of Industry 5.0 from various perspectives. The paper also identifies the challenges and opportunities for future research and practice in this new paradigm.
28.	Leng et al. (2022)	This paper reviews the evolution and key characteristics of Industry 5.0: human-centricity, sustainability, and resiliency. The paper proposes a tri-dimension system architecture for implementing Industry 5.0, discusses key enablers, future implementation path, potential applications, and challenges. It also highlights the limitations of current research and potential future research directions.
29.	Breque, De Nul, and Petridis (2021)	The authors discuss Industry 5.0, which aims to create a sustainable, human-centric, and resilient industry in Europe. The publication highlights the role of research and innovation, the value of new technologies, and the respect for the environment and workers.
30.	Möller, Vakilzadian, and Haas (2022)	The paper explains the development from Industry 4.0 to Industry 5.0. It discusses how IoT, and digital technologies have enabled the automation and customisation of production processes in Industry 4.0. It also explains how Industry 5.0 aims to achieve sustainability, circular economy, and human-centricity in manufacturing.

Appendix 2. Classification and groupings of extracted statements

Main themes	Extracted statements
Theme 1: Guaranteeing physical and mental well-being in the workplace	Empowered and interactive roles for shop floor and supervisory employees; Empowered workers; A more stimulating work environment; Work environments should be designed to enhance both productivity and work well-being; Digitalising industrial processes enables remote work; Guaranteeing workers' physical and mental health; Digital solutions and wearables to encourage adoption of healthier lifestyle and for alerting workers and their general practitioners about critical health conditions, both physical and mental; Job satisfaction; Reduce work injury; Greater employee autonomy; Emphasis on workplace safety with the use of next-generation technologies or human–machine relationships; Workers can pursue their professional growth and achieve a better job satisfaction; Designing for well-being that focuses both on job satisfaction and work engagement; Technological advancements promotes workers well-being; Designing for well-being that focuses both on job satisfaction and work engagement, opportunities for personal development; Workers would have more accountability; Technology serves workers and prioritising their wellbeing.
Theme 2: Meeting social, autonomy and ethical considerations	Protect workers' rights; Guaranteeing workers' autonomy, human dignity and privacy; Technology does not undermine, explicitly or implicitly, the dignity of the worker, regardless of their race, gender or age (bias); Technology does not impinge on workers' fundamental rights, such as the right to privacy, autonomy and human dignity; Workplace dignity; A focus on social and ethical considerations.
Theme 3: Inclusive workplaces	Not to leave anyone behind; Safe and inclusive work environments; Inclusive workplaces; Development of inclusive workplaces; Inclusive work environment; Operator's individual differences should be considered when putting together humans and automation to take advantage of each other's strengths; Technology used in manufacturing is adapted to the needs, and diversity of industry workers, instead of having the worker continuously adapt to ever-evolving technology; Smart technology to be personalised and transformed to meet workers unique value need; Technology will consider the needs and diversity of workers; Embrace the characteristics and preferences of individual workers, to promote workplace inclusiveness; Introducing more people with reduced mental abilities in the working environment by allowing them to access assistance of appropriate technologies; Elderly employees to work more and be more effective at work.
Theme 4: Participatory design approach	Workers are to be closely involved in the design and deployment of new industrial technologies, including robotics and AI (codesign); Workers are involved in every step of digital transition; Prioritising employee's capabilities and change-readiness before adopting an innovative technology rather than enforcing their autonomy on the employee.

Theme 5: Humanising technology for a workplace that is a meaningful sociotechnical system	Creating meaningful and sustainable socio-technical systems; A forward-looking perspective for the need of engineers' and workers' skills, knowledge, and abilities to cooperate with machines and robots on the one side, and flexibilities in manufacturing processes and environmental impacts on the other; Concentrate on human factors when implementing new technologies in industrial systems; Industrial systems is designed for human values, rather than relegating them as an afterthought; Human needs and interests at the core of the production process; Core human needs and interests at the heart of the production process; Human employees and their different needs from physical to mental needs are valued
	human needs and interests as the core of the manufacturing process; Examine human values and ethical considerations a priori so that they are not treated as costs but as design requirements; Manufacturing and production technology is redesigned to better reflect human needs and values; putting human and its needs as the first priority; Prioritising core human worker needs while maintaining or improving industrial productivity; Focus shift from shareholder value to stakeholder value; Worker is not to be considered as a 'cost', but rather as an 'investment'; Workers are considered 'investment' instead of 'cost'; A shift from technology-driven progress to a thoroughly human-centric approach; A shift of focus from technology driven progress to a human-centric approach; A 'human-centered' rather than a 'techno-centered' approach; Technology is mostly implemented to extend human capabilities and support the worker to make the right decision; Realise human value rather than replace them; Technology serves people; Shifting from a traditional task-centric production to a worker-centric production; Worker in the centre of the production systems; Recognise what technology can do for the people and focus on how technology can adjust to the requirements of the worker instead of the other way; Brings back the human to the factory floor; Technology that adapts to the worker, rather than the other way around; Adapting to the workers' needs; Technology to adapt the production process to the needs of the worker, e.g. to guide and train him/her; Technology is more intuitive and user-friendly, so that workers would not require specific skills to use it.
Theme 6: Investing in skills and human capital	Upskilling and reskilling; Investment in skills, capabilities and the well-being of employees; Facilitate a shift in some workers' qualifications, i.e. to re-skill them; Human is upskilled to shift from manual to cognitive labour; Assume that workers may not acquire all the knowledge of the working machine; Workers education, training, re-skilling and up-skilling; Investment in skills and human capital by companies by providing education and training of the workforce.
Theme 7: Emphasis on creative thinking	Human to put full effort in creativity and innovation; Enable humans to unleash their critical thinking, creativity, and domain knowledge; Creative human touch on the production instead of a standard robotic production; Leverage the unique creativity of human experts to collaborate with powerful, smart and accurate machinery; Allow for creativity in the work process to be boosted by encouraging everyone to innovatively use different forms of robots in the workplace; Humans set the strategy, provide oversight, and add creative input; Helping workers better utilise their expertise and creativity
Theme 8: Role of humans in the human-machine relationship	Collaborative robots collaborate with operators instead of competing; final decisions are being made by humans); Cobots complementing humans; Humans delegate most of the physical tasks to machines/robots and focus more on the high-level decision-making and AI training; Human intelligence can be applied for critical thinking of the customisation logic, and the cobots can be utilised for labour-intensive tasks; Humans provide value-added tasks in production and to work with autonomous workforce (cobots) that is perceptive and informed about human intention and desire; The human help to support and improve AI's performance; Workers will assume better roles on the factory floor; Create more jobs than it takes away (in the intelligent systems arena, AI and robotics programming, maintenance, training, scheduling, repurposing, and invention of a new breed of manufacturing robots).
Theme 9: Cobots and robots for mundane and repetitive tasks	Cobots assist people in doing routine activities; Assigning repetitive and monotonous tasks to the robots/machines and the tasks which need critical thinking to the humans; Assigning repetitive and monotonous tasks to the robots/machines and the tasks which need critical thinking to the humans; Coexistence and cooperation between human & robot (human is on creative and transformational parts and that robots will be of transactional and repetitive work;Technology performs the mundane, repetitive, error-prone tasks; Alleviating the weakened manpower by effective use of cobots for labour-intensive jobs; Cobot will take care of the repeated activities; Machines can be trusted to autonomously assist on repetitive tasks with high efficiency, anticipating the goals and expectations of the human operator; Collaborative robots perform repetitive and dangerous jobs while people focus on creativity and efficient business solutions; Robots could take over a number of repetitive and simpler tasks and make certain task less physically demanding- making workplaces safer for workers.
Theme 10: Cobots and robots communicate in the form of human-intelligible narrative	Robots to communicate present and future activities in the form of human intelligible narratives; Robots capable of understanding the increasingly coupled relationships between humans and machines in unstructured environments; Automated labour (machines) will be able to detect and inform human purpose, desire, need, and safety; Machines must have an 'understanding' of human co-workers actions and future movements for health and safety & productivity reasons; Cobots to analyse the human intent before the analysis of the task itself and should understand when its collaborative human needs help; Human companion (cobot) that will already know, or quickly learn, what to do (like an apprentice); socially intelligent factory (cobots converse with people); Matching human intelligence with machine intelligence and training the cobots to adapt to a sweeping change of the human brain while co-working; Synergy between humans and autonomous machines that are perceptive and informed about human intention and desire.
Theme 11: Synergistic and symbiotic relationship between humans and machines	Robots and innovative technologies are designed in a human-centric way; Introducing the human factor into cyber-physical systems (Human Cyber-Physical System); Increased self-resilience of human workers by using technology to augment cognitive, physical and safety; Human backup – when (human) operators should backup automation when there is a context change that automation is not sensitive to; human-in-the-loop – when there is a need for rapid cognition and creative option generation; Humanised design to bring closer the relationship between humans and machines; The robots and skilled labour to work together; Increased system resilience trough adjustable autonomy and control between human and machine; Expanding the capabilities of the industry worker with innovative technological means, rather than replacing the worker with robots; From the old task distribution model to a collaborative intelligence model; Treating automation as a further enhancement of the human's physical, sensorial, and cognitive capabilities; Support and empower, rather than replace workers; Combining workflows with intelligent systems; Facilitates the robots and skilled labour to work together; Restructures human tasks in the realm of manufacturing in ways that benefit the workers; Connect and combine the strengths of humans and machines; Merges the high speed and accurate machines and critical, cognitive thinking of humans; The primacy of the Human worker is respected and augmented through tailored use of digital technologies to enable skills acquisition and deployment rather than complete replacement with automation; Intimate partnership between man and machine through more humanised and intelligent design, such as empathy machine; Cooperate with the CPPS and complement the robotic and virtual world of the automated production system; Cooperation between human intelligence and cognitive computing; Mutual-cognitive coordination between human intelligence and artificial intelligence in machines (which actively enhances each other's complementary strengths: the intuition, leadership, teamwork, creativity, versatile problem-solving, and social skills of workers, and the speed, scalability, endurance, and quantitative accuracy capabilities of machines) to co-innovate, co-design, and co-create individualised products and services; Collaboration of human and artificial intelligence; Synergy between humans and autonomous machines; Humans and robots co-work; Synergistically combining human and robot abilities; Collaboration between humans and machines on the factory floors; encourage collaboration between humans and a new generation of robots (cobots); Coevolution interaction between AI and human; man–machine symbiosis - synergies among the human workforce and smart machines; Machines and humans in a synergistic collaboration to increase productivity in the manufacturing industry while retaining human workers; Trustworthy coevolutionary relationships between humans and machines; Humans will be guiding robots.

Appendix 3. List of questions for the semi-structured interview (excluding demographic questions)

Section I. Initial perception of Industry 4.0 and Industry 5.0

1. Can you please introduce yourself and provide an overview of your professional experience?
2. What specific areas or domains have you primarily focused on throughout your career?
3. How familiar are you with the concept of Industry 5.0? Could you provide a brief overview of what Industry 5.0 means to you?
4. Have you been involved in any projects or initiatives related to Industry 5.0 or the adoption of advanced technologies? If yes, could you briefly describe your involvement and contributions?
5. From your understanding, what are the key differences between Industry 4.0 and Industry 5.0?
6. What does the term "human centricity" mean to you in the context of Industry 5.0? How do you see human centricity playing a role in the development and implementation of Industry 5.0 technologies?

Section II. Challenges and importance of human-centricity in Industry 5.0

Now, I will present to you a concept related to human-centricity vision in Industry 5.0 (a mind map which represents the concept of human-centricity in Industry 5.0 is shown to the participant). Participant will be given 5 minutes to observe the mind map and ask questions before the interview resumes.

1. Taking into account the mind map shown to you earlier, in your opinion, why is it challenging to incorporate human-centric principles into Industry 5.0? What are the main barriers or obstacles that organisations face in achieving human-centric approaches in this context?
2. How do you perceive the importance of human-centricity in Industry 5.0?

Section III. Human Factors in Industry 5.0

1. In your view, what are the main contributions that the human factors field can make in advancing the readiness of Industry 5.0 in terms of human centricity?
2. How do you perceive the readiness of the human factors field in addressing the human-centric aspects of Industry 5.0? Are there specific gaps or areas that need further attention and development within the field?

Section IV. Reflection on the Human Factors profession

1. What do you believe are the most critical skills or competencies that human factors practitioners should develop to effectively navigate the changing landscape of Industry 5.0 that prioritises human centricity?
2. How do you stay updated with the latest trends and developments in your profession?
3. Have you participated in any research, conferences, or workshops related to human centricity in the context of Industry 5.0? If so, could you share any key insights or learnings from those experiences.
4. Have you collaborated with other experts or organisations in the field to promote human-centric approaches in Industry 5.0? If yes, could you share any notable collaborations and their outcomes?