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Defining Human-centredness – a systematic review

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Abstract Since the introduction of the Industry 5.0 concept in 2021 research attention to "human-centeredness" has increased significantly. Fourteen thousand articles mention the concept, but it is often vaguely defined. In this study a systematic review was conducted, and 96 articles including Human-centeredness, Industry 5.0 or Industry 4.0 and definitions in them were reviewed. The aim was to clarify how human-centeredness can be defined and operationalized. It was seen that only 12 papers provided a definition of human-centeredness; three included a general definition and 11 included specific definition e.g. human-centered digital twin or human-centered AI. Human-centeredness is applied in many different settings, from manufacturing to human-centered AI. In the analysis differences and similarities of the found definitions were studied, investigating the level of detail, aspects included in the various definitions, and how the definitions vary across the applications of the human-centeredness, e.g. human-centered AI and human-centeredness cyber-physical systems. A definition was suggested that could support practitioners and make human-centeredness less vague and provide guidance for how to work with human-centeredness in industry. This is important not least for human-centered manufacturing and for aligning work towards the vision presented in Industry 5.0. Keywords: Human-centeredness; Industry 5.0; Industry 4.0; Systematic review.

1. Introduction

The emergence of Industry 5.0 in 2021 by the European Commission has brought increased attention to humans and their wellbeing in industrial development. In contrast to Industry 4.0, which was strongly technically-driven (1), focusing on, e.g., technical advancements, cyber-physical systems, automation, data exchange, and smart manufacturing, the Industry 5.0 concept seeks to shift the focus towards humans, resilience, and sustainability (2). The shift in focus suggested in Industry 5.0 reflects a growing recognition that technological progress should not only give attention to efficiency but also enhance, for example, human well-being, creativity, and agency when designing technologies and systems. A core dimension of Industry 5.0 is a *human-centric approach* (3). Human-centeredness has been given significant attention in recent academic publications and discussions as well as in industry (4). Using the query human-cent* AND "Industry 5.0" OR "Industry 4.0" in Scopus yields 14 452 results as of October 2025.

Despite the attention given to it, human-centeredness remains a rather vague concept, lacking a clear, unifying definition (5). In the Industry 5.0 report, it is stated that "a human-centric approach in industry puts core human needs and interests at the heart of the production process" (3, p.14). Although this statement provides an idea of what human-centeredness involves, it is not fully what the concept entails. And although many studies are performed within human-centeredness not many of them prove that they are in fact human-centered. It also does not provide guidance on how to operationalize the concept for practitioners in production environments. Mata et al. (6) state that there is a need to support practitioners concerning human-

centric initiatives through courses and events. Bolis et al. (7) suggest that there is a need for frameworks to guide organizations in Industry 5.0. The authors further state that it is crucial to identify and define indicators to measure and improve human-centered performance. It can also complicate research efforts both within disciplines and in interdisciplinary research as human-centeredness may be defined and evaluated differently as well as cause misunderstandings and confusion (4,8). Additionally, there is a wide array of similar or interchangeable terms that add to the ambiguity and lead to diverse interpretations for example, human-centricity, human-centric, human-centered, and user-centric.

Establishing a clear and shared definition of human-centeredness is important for aligning various stakeholders, guiding the design of technologies and systems, and enabling evaluation of outcomes (7). A well-defined concept of human-centeredness is crucial in research, ensuring that scholars from diverse fields as well as in the same field share a common understanding when addressing the concept. This shared clarity is important for the development of systems and technologies that genuinely place humans at the center of design and implementation, as envisioned in Industry 5.0 (5).

Therefore, the aim of this paper is to clarify how human-centeredness can be defined and operationalized connected to Industry 5.0 and 4.0. This will be reached through two objectives: i) To systematically assess how many definitions of human-centeredness that are used in literature connected to Industry 5.0 or Industry 4.0. This study does not include other words that are synonymous to "define" and focuses specifically on industrial applications of AI that are human-centric, and ii) To present similarities and differences in the definitions and discuss how human-centeredness should be defined in this context. From the identified definitions, the paper then seeks to suggest a new definition of the concept that is pragmatic, i.e. practitioners should be able to use it to state what competences that are needed to form a team that could support the implementation of a human-centered technology in industry.

The paper is structured as follows: In the next section this section the aim and objectives are stated then relevant available models of human-centeredness are presented. In section 2 the methodology and sample of the systematic review are introduced and in section 3 the results are given. In section 4 a discussion of the results follows, and section 5 consists of a brief conclusion section. The paper ends with acknowledgements and references.

1.1 Understanding human-centeredness

In 1997 Billings (9) coined **human-centered automation (HCA)** which was defined as an "automation designed to work cooperatively with human operators in the pursuit of stated objectives" (p. 7). It was developed for managing aircrafts and air traffic and the purpose was to decrease the "likelihood of human or machine misinterpretation of system state or misunderstanding of which element is performing each of the many functions necessary for safe mission completion". HCA is used to characterize automation use i.e. through technology use (10) and the goal is to enhance humans that are responsible for safety and effectiveness in complex dynamic systems. Technology should hence support capabilities and compensate for human limitations. Similarly, **cognitive engineering** is focused on understanding a user's issues and identifying trade-offs that make a better and more useful system (11). Another term, **user experience** instead focuses more on human perception and responses to an interaction with a product, system or use of a service (12). In 2019 the **ISO9241-210**, Human-centered design for interactive systems, was presented (13). Here, human-centered design is defined as "… an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics,

and usability knowledge and techniques". The standard is built upon ISO 13407:1999 which has been validated through ten years of application (13). The new standard has some differences compared to the older one and includes requirements and recommendations. The new standard empathizes with the involvement of all stakeholders in the design as well as focusing on both users, tasks and environments. In addition, ISO9241-210 also states that users should be involved throughout the design and developments, that the design should address the whole user experience and that they are included in the evaluation of the design. In comparison the older standard mentioned allocating a function between users and technology which is not empathized in ISO9241-210. Both standards build upon human factors/ergonomics as well as usability and include the following relevant terms: accessibility, context, efficiency, effect, ergonomics, interactive system, satisfaction, user experience, interface, validation and verification. Both standards also stressed that a multi-disciplinary team should be included in the design.

2. Methodology

The method used in this article is *systematic review* which in comparison to a literature review aims to find not only well cited papers but also papers that are less cited which makes the review unbiased (14). This method enables a structured and comprehensive analysis of existing definitions across disciplines, providing a solid foundation for establishing a clear and actionable definition of a term. The purpose of the study has been presented in the introduction. Figure 1 presents the PRISMA statement for the review.

The search query used was ("human cent*" W/10 "defi*") AND ("Industry 5.0" OR "Industry 4.0"). The search query uses wildcards (the * is used in Scopus) to broaden the search, this helps capture variations of a word and ensures more comprehensive results. This is done since there are many terms that are used for human-centeredness, for example, human-centric, human-centricity, human-centeredness, human-centeredness, human-centered; The wild card * was used to find all relevant terms related to human-centeredness. The same logic was applied to the definition as there are several ways in which the word can be written as a noun definition or as a verb: define, defined. The use of the wild cards in the search query ensures that potentially relevant papers are not excluded due to different ways in which the words may be spelled.

Fourteen thousand documents were found using the search query "human cent*" AND ("Industry 5.0" OR "Industry 4.0"). When adding AND def* 6700 documents were found. The criteria for inclusion were therefore that the word define/defined/definition is used within ten words to "human-cent*". The operator "W/n" finds paper that include human-cent* within ten words of defi*. There are many words allowing for sentences where human-centered is first introduced but may be defined in the following sentence. As definitions of human-centeredness are rarely present in the abstract or title of an article, the search query was used in all fields, i.e. was not restricted to for example title, abstract and keywords searches to identify definitions of human-centeredness anywhere in the text of the papers. The search resulted in 96 papers and because of this the prompt was not limited by fewer words. The use of the W/ operator is particularly appropriate in this context as it allows for the retrieval of sources where the term human-centeredness appears in close proximity to words such as definition. This proximity-based search increases the likelihood of identifying papers that explicitly define human-centeredness, rather than merely mentioning it in passing. This approach was chosen to increase the number of papers that are likely to contain explicit definitions.

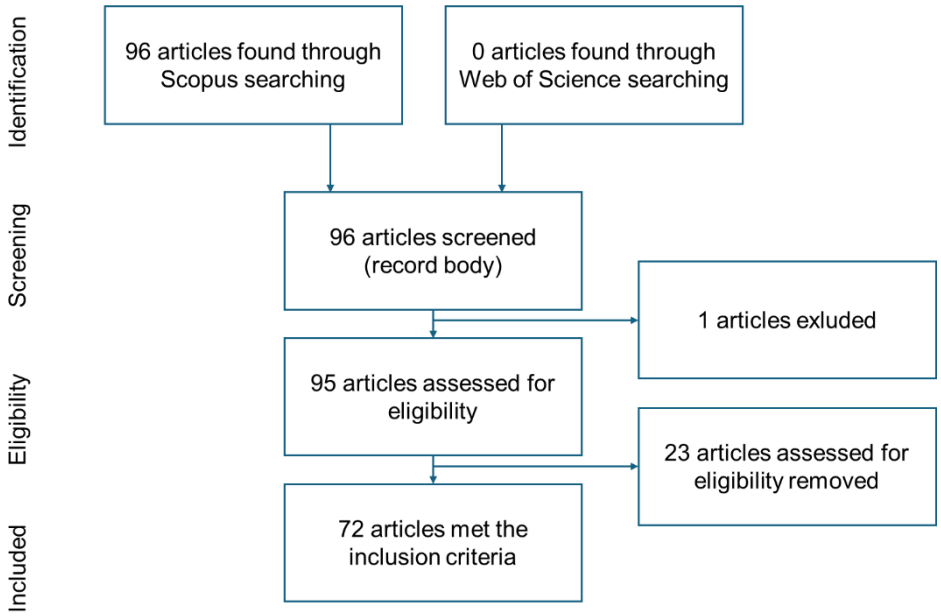

Figure 1: PRISMA 2020 statement for the systematic review (14).

During the review two reviewers assessed the literature independently and if something was unsure, they together discussed if the paper should be included or not. The exclusion criteria were: duplications and if the def* does not stand for define but instead deficiency or another word. The studies will be screened through finding "defi*" in literature and then identify if human-centeredness has been identified. The 96 articles that met the inclusion criteria were screened for clear definitions of human-centeredness. Some of these papers do not use the term definition in relation to human-centeredness but still provide a clear conceptualisation of human-centredness, for example, some papers clearly labelled their definitions (e.g., "we define human-centredness as…"), others provided conceptual descriptions or operationalizations without using the term "definition". These were included if they offered a clear statement of how the term was understood or applied within the study. This approach, combining a focused search query with inclusive screening criteria, ensured relevance in the final dataset of included definitions. The eligibility criteria is that only papers, conferences and journal papers are included; hence, books are excluded from the analysis.

The 72 articles that met the inclusion criteria were included in the review. When the review was performed the definitions will be counted and then similarities and differences will be found. The goal is to find a definition that could be used for future studies; this definition will be derived from the analysis.

3. Results

In this section the results of the systematic review and the analysis are presented.

3.1 Systematic review

The systematic review showed that 83% lacked a definition (n=60). In twelve papers a definition of human-centeredness was found. In Table 1 the types of definitions found are summarized. Seven specific and three general definitions were found.

Table 1: Type of definitions found: Does not have a definition, general definition or specified definition.

Description	Number of articles
Does not have a definition	60
General definition	3
Specific definition	11

In two of the identified papers with definitions, two definitions concerning human-centricity were found, hence the total number of definitions found was 14. Most of the specific definitions are found concerning AI or production related aspects i.e. CPPS, digital twins and assembly. One definition concerned design. The specific definitions are presented in Table 2.

Table 2: Specific definition found. The different types are AI, production related, or design related.

Specific definition found	Number of definitions found	Description (if needed)
AI	5	
Production related	4	CPPS, digital twins, manufacturing, and assembly
Design and methodology	2	

Table 2 shows that human-centeredness is used for many different applications: design, methodology, digital twins, cyber-physical systems, assembly, and AI showing that the concept is relevant in many fields. There are also several papers that define human-centeredness on a general level. All found definitions are presented in Table 3.

Table 3: The definitions that were identified in the review are presented.

ID	Definition	Comment	Ref
D1	*Human-centered cyber-physical production systems (H-CPPSs)* are defined as systems that support humans, machines, and software to integrate virtual and physical worlds.	Cyber physical systems	(15)
D2	*Human-centric* AI is defined as "AI tools that prioritize and enhance the human experience by making them more intuitive, empathetic, and aligned with human values and needs".	AI	(16)
D3	Although plenty of definitions of DTs (Digital Twins) already exist, this research seeks to define a DT from a human-centric point of view, considering the cognitive interactions between people and DTs, and DT user requirement levels.	Digital Twins	(17)
D4	*Human-Centric* Artificial Intelligence (HCAI) emphasizes that AI systems should enhance and complement human abilities rather than replace humans. It focuses on the interaction between humans and AI, aims to improve human well-being, and ensures that AI technologies are consistent with human values and needs. HCAI prioritizes user experience and ethical considerations by following three principles: being inspired by human intelligence, guided by human impact, and augmenting human capabilities.	AI	(18)
D5	… *a human-centric methodology* is defined to provide design guidelines and successfully select the most proper digital tools supporting the Operator 4.0, placing humans at the center of the digitalization processes, and not starting from the technology capabilities as implemented in literature so far. Indeed, a human-centric approach ensures that the ethical considerations of sustainable practices and circular economy principles are upheld, aligning technological advancements with societal values. Moreover, enhancing the op erators' skills through dedicated training programs and adaptive interfaces will foster a seamless integration of technology, making the transition to I5.0 more intuitive and valuable	Human-centric methodology	(19)
D6	11 aspects of *human-centeredness* in Industry 5.0: 1) Synergistic & symbiotic relationship between humans & machines 2) Cobots & robots communicate in human-intelligible narratives 3) Cobots & robots for mundane & repetitive tasks 4) Role of humans in human-machine relationship 5) Emphasis on creative thinking 6) Investing in skills & human capital 7) Humanising technology for a workplace that is a meaningful socio-technical system 8) Participatory design approach 9) Inclusive workplace 10) Meeting social, autonomy & ethical considerations 11) Ensuring physical and mental wellbeing at work	General definition	(5)

D7	Core principles of *human-centric AI*: • Human empowerment • Transparency • Explainability • Fairness • Equity • Data security • Responsibility • Autonomy • Ethical	AI	(20)
D8	… *HCD* is defined as an 'approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques'.	Design	(21)
D9	*Human-Centered AI (HCAI)* focuses on understanding purposes, human values, and desired AI properties in the creation of AI systems by applying Human- Centered Design practices. HCAI seeks to augment human capabilities while maintaining human control over AI systems, by considering the necessity, context, and ethical and legal conditions of the AI system as well as promoting individual and societal well-being.	AI	(21)
D10	"..*human-centric assembly* (HCA)..within smart factories would be facilitated by four enhanced human abilities of augmented robots, cognitive systems, mixed reality (MR), collaborative intelligence (co-intelligence), and human thought-driven assistance of brain robotics. The four enhanced human abilities are expected to energise, advise, support and empower a human operator physically and intelligently. Brain robotics driven by human thoughts together with sensing-enabled context awareness further allows an operator to best perform HCA tasks through real-time perception, robot assistance and human knowledge.	Assembly	(4)
D11	*Human-centricity* is a multidimensional framework that places human needs, characteristics, motivation and experiences at the centre of design, development, and implementation of technological solutions and organisational practices that not only meet functional requirements but also enhance human well-being, capabilities, skills, and working conditions.	General	(22)
D12	*human-centric enabling technologies* .. "denote technologies with the potential to contribute to human centricity".	Technologies	(22)
D13	*Human-Centric AI (HCAI):* HCAI should be designed with the use case relevant SDGs in mind, to promote the greater good.	AI	(23)
D14	In the industrial sector, *human-centric manufacturing* is a significant approach emphasising humans' role in the manufacturing process, integrating their skills with technology to address challenges such as worker shortages and competitiveness.	Manufacturing	(8)

3.2 Analysis

Human empowerment and enhancement are mentioned by four definitions (D2, D4, D10, D11 and D13). In these definitions human capabilities are enhanced. This is mentioned in the Industry 5.0 vision and is also stated as one key focus of HCA (10). In addition, the implementations in the definitions are often collaborative or interactive in its nature. Another similarity is that some definitions address ethics, fairness or societal values i.e. this is seen for two of the AI-definitions and three definitions state that the design for interaction is central i.e. D2, D3 and D4. Human-centered AI has the most definitions in the review conducted in this paper with four different definitions (D2, D4, D7 and D9).

Differences are seen in the focus, technology use, human role and design approach. D1 and D10 focus on the integration of humans and technology in a smart factory while e.g. D5 and D9 focus on how the system aligns with human values and D3 on cognitive interactions. Technology used or addressed also differs i.e. CPPS, AI, digital twins and technology for assembly systems are different and could have very different ways of interacting or existing together with a user. The human role also differs. For the D1 the user is active in the system integration. Similarly, for D3, the user is a cognitive partner in simulation and decision-making. In D10, the human is instead enhanced and empowered by the system and e.g. in D9 the user controls the system. In this sense D10 has an ergonomic participatory design. D3 also focuses on ergonomics but has a cognitive ergonomics approach while D1 has a system level integration approach. For the AI definitions there are also differences between the definitions. The D9 definition is broader for example, including also legal conditions of AI systems as well as not only human well-being but also societal well-being. The other definitions are on a more individual level.

The identified definitions also differ in terms of how concrete and detailed the definitions are. D1 is broad and on a high level and does not provide many details or how to operationalize it. The definition D11 provides more detail and gives indications on the outcome of human-centric design and implementations. The definition of (5), D6, is even more detailed by dividing human-centricity into 11 aspects, where each aspect is clearly explained. D14 is also very detailed concerning human-centered manufacturing. And D6 presents 11 aspects of human-centeredness and provides more detail into both the machine interface as well as the human needs, skills and well-being. In comparison, the ISO-standard for human-centered design is comprehensive and mentions several of the approaches seen in the definitions e.g. focusing on the user and all stakeholders, applied human factors, ergonomics (D8 and D3) and user experience (D3) but it also mentioned the iterative design throughout the whole design process; this also includes the evaluation. D13 connects the definition to the sustainable development goals from the UN.

3.3 Definition

Based on the analysis the definition could include the view of the human in the center and that the human is supported or even enhanced by interacting or collaborating technology. How the human is enhanced should be able to vary since not all interactions are the same and all stakeholders should be included in such a definition (13) (ISO 9241-210:2019). Ethics and societal values are also sometimes included. However, if the definition should work in the context of Industry 5.0 and societal values are already included in the social sustainability, then this is not needed in the human-centric definition. If, however, the definition should work on its own, then this is a relevant factor to include. The focus of integration needs to be varied since human-centricity should include many different technological implementations. The design approach should also be able to vary; however, it should support the included factors in the definition. Hence the following definition is suggested: **Human-centeredness is defined as the approach to**

implement interactive or collaborative technology where human capabilities are supported or enhanced. Aspects that should be included in the approach are usability analysis, iterative design and evaluation and ethical considerations.

The design approach should capture all human stakeholders' needs through e.g. interviews or observations, involve the operator in the implementation through all stages i.e. design, implementation and evaluation and consider ethical and/or societal aspects. In addition, the implementation work should be carried out with a multi-disciplinary team e.g. technology provider, operations, maintenance personnel, managers, HR and IT-specialists.

4. Discussion

The aim of this review was to investigate how human-centeredness has been defined in the context of Industry 4.0 and 5.0. This means that human-centeredness mentioned in other contexts is limited from this review e.g. there could be many definitions that could be suitable for an industrial context that was not included. In the Introduction relevant references that have been used in the context were added such as the ISO-standard were added. Some findings also include previous reviews done of human-centeredness and the authors believe that although not all definitions for human-centeredness were found, the most relevant were.

The paper shows that there are different definitions of the term used in literature and the concept is used in different applications. An interesting finding is that most of the papers in the review lacked a clear definition of human-centeredness. Hermawati et al. (5) conducted a thorough systematic literature review to come up with a definition for human-centricity (D6). In total 30 articles were included in their analysis. The authors also perform a thematic analysis and suggest 11 aspects of human-centricity. However, the search query used specifically focused on "human-centricity". As established in the introduction, there are many similar or interchangeable terms such as human-centeredness, human-centered (8). By only searching for human-centricity there is a risk that relevant definitions are not found. The search query applied in this paper, using wild cards, includes different terms. The review conducted in this paper thus contributes to the review of (5) by capturing a broader set of interrelated terms concerning the human-centeredness concept.

A noteworthy finding of the literature review is that of the 96 papers that were screened in the literature review, 60 of them did not have a definition of the concept at all but still applied the concept within their studies. By not defining the concept clearly it is up to the reader to make sense of the concept in the study, which may cause misinterpretations (8). There is also a need to guide various stakeholders, and support is given to practitioners (6,7).

4.1 Defining human-centeredness

Going through the suggested definition word for word it is structured similarly to the ISO-standard for interactive systems but is simplified i.e. using the word approach to describe what human-centeredness is. This is done since the word 'approach' is believed to be easy to understand by researchers and since it is used in the standard, it should be a well-known way to start the definition. In the ISO-standard the word interactive systems are used which the authors wanted to simplify. Instead 'interactive or collaborative technology' is used which are terms often used to describe technology used in Industry 4.0/5.0 context. The next part of the sentence states how humans are addressed in this approach. Since most definitions emphasize that human capabilities should be enhanced, this was included in the definition. This was strengthened by adding the word 'supported' which the authors believe is key. This is in line with the Industry 5.0 vision stating that

attention should be given to enhance human well-being, creativity and agency in the design of technologies and systems (3). Due to the fact that the definition also includes what aspects should be included and how they should be included in a design approach, the definition could also support practitioners that are in need of support in regard to human-centric initiatives (6). The following sentence is again influenced by the ISO-standard but uses method names which the authors believe will guide researchers and practitioners in their work towards applying such methods in their human-centric implementations i.e. 'usability analysis, iterative design and evaluation'. This way the authors believe that human-centeredness can be better operationalized in industry. Finally, 'ethical considerations' were added since many definitions include this and it is crucial to consider in an industrial setting.

The suggested definition is better than the definitions identified in the literature since it is based on an existing and validated ISO-standard and includes words appropriate for researchers and practitioners working in the industrial context. In addition, the methods and models used to operationalize human-centeredness have been added which was not seen in previous definitions. The authors believe that the definition this way both provides clarity and guidance to support target groups in achieving human-centeredness in industry.

Since the suggested definition is less detailed than some of the identified definitions it is advised that if the implementation is in assembly D10 could be used since it is more detailed in this area. In addition, if the technology implemented is AI the 11 core principles in D7 could be useful. The 11 aspects of human-centeredness could be useful when implementing solutions that include higher levels of automation e.g. robot or human-machine collaborations. This definition also addresses physical and mental wellbeing (D6). When there is a need to go more in-depth into studying ergonomics and human factors D8, D3 or D6 could be useful. From a practitioner perspective going in-depth or using the available ISO-standard might be too comprehensive.

4.2 Contribution for practitioners

The 14 definitions found contain similar factors as the models i.e. the ISO-standard terms (13), the user experience and the vision for Industry 5.0 (3). The suggested definition includes aspects of them but excludes details and e.g. cognitive ergonomics and specific human factors. This is since the suggested definitions should include aspects that are operational that practitioners could understand. The suggested definition should serve as a basis for how practitioners can implement technology in a human-centered way but also give them hints on where more work is needed and how the work can be operationalized i.e. through stating what should be included in the work i.e. usability analysis, iterative design and evaluation and ethical considerations. By pinpointing where work is needed the practitioner working as e.g. a production technician or running a digitalization project would know what competences should be included in an implementation team. The type of roles in the multi-disciplinary team is also suggested. This could help guide different stakeholders and support practitioners as needed.

4.3 Limitations and future research

The search query utilized in the paper has limitations. Firstly, there is a limitation of adding Industry 4.0 or Industry 5.0 to the search string. This way, definitions that could be relevant were not included. Another limitation regards the W/n operator. While the W/ operator is effective for identifying instances where human-centeredness is discussed in close relation to definitional terms, a potential criticism is that it may exclude relevant papers where these terms are discussed in separate parts of the text, more than 10 words apart. Given the aim of this review is to identify explicit definitions of human-centeredness, the use of W/ is justified as it increases the precision

of the search. To mitigate the risk of missing relevant literature, complementary searches using broader queries were also conducted and screened manually including ISO 9241-210:2019 and reports from the EU commission concerning Industry 5.0. Secondly, there could be synonyms of the word definition used within the papers. Instead of “define” words like “refers to” or “is characterized” could be used to explain human-centeredness within a given paper as identified in the analysis of this paper. The review of for example Hermawati et al (5) is limited by this issue as well as the word definition is included in their query. In their review there is also no wildcard used. In addition, since books are excluded from the eligibility criteria some definitions could be missed.

The definition should be further tested with researchers, practitioners and other key stakeholders iteratively to ensure that it includes the right wording as well as so that it is both comprehensive and simple enough to understand and use. This is part of the future research. In addition, this study has focused on definitions of human-centeredness in the context of Industry 4.0 or Industry 5.0. There are other concepts that have been applied in research that relate to human-centeredness, for example user-centric, human-robot collaboration, human-robot interaction, operator 4.0, as have been identified in the review of papers. In the future, the differences and similarities between the social sustainability dimension, resilience and the human-centric aspects of Industry 5.0 could be further elaborated on. There are overlapping aspects between these two as seen in some of the identified definitions. Future research could also assess the concepts studying differences and similarities between them, disciplines where these concepts are applied, methods used to adopt technology with them and current trends within these concepts.

5. Conclusions

Even though human-centeredness is mentioned in over 14 thousand papers the study shows that of the 72 papers that mention definition within ten words of human-cent* only ten present a definition of the concept. In this paper the following definition was suggested: **Human-centeredness is defined as the approach to implement interactive or collaborative technology where human capabilities are supported or enhanced. Aspects that should be included in the approach are usability analysis, iterative design and evaluation and ethical considerations.** This definition together with practical suggestions could support practitioners i.e. what design approach that could be taken and what roles could be included in a multi-disciplinary team that implements a human-centered solution.

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