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Original scientific paper

BRIDGING THE GAP: QUALITATIVE COMPARATIVE ANALYSIS OF INDUSTRY 4.0 AND INDUSTRY 5.0

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A b s t r a c t: The fourth industrial revolution comes with a lot of promises for the future of effective and efficient manufacturing. However, in the light of the rapid change of the technology, smart manufacturing is undergoing transformation driven by two distinct paradigms: Industry 4.0 advocates for the shift to-wards digitization and automation, while the emerging Industry 5.0 prioritizes human-centric approaches. Currently, there is a need to consider sustainable development and the crucial role of humans in the assumptions of industry's future development. Concerns about the implementation of digital technologies became the basis for building the assumptions of Industry 5.0. This article will present a comparative qualitative compassion between Industry 4.0 and Industry 5.0 in order to precisely characterize both concepts.

Key words: Industry 4.0; Industry 5.0; digitalization; comparison

СПОЈУВАЊЕ НА РАЗЛИЧНОСТИТЕ: КВАЛИТАТИВНА СПОРЕДБЕНА АНАЛИЗА НА ИНДУСТРИЈАТА 4.0 И ИНДУСТРИЈАТА 5.0

А п с т р а к т: Четвртата индустриска револуција доаѓа со многу ветувања за иднината на ефективно и ефикасно производство. Сепак, во согласност со брзата промена на технологијата, паметното производство претрпува трансформација водена од две различни парадигми: Индустрија 4.0, која се залага за пренасочување кон дигитализација и автоматизација, и Индустрија 5.0, која им дава приоритет на човечкиот фактор и одржливоста. Во моментов постои потреба да се разгледаат одржливиот развој и клучната улога на луѓето во претпоставките за идниот развој на индустријата. Овој труд прикажува квалитативна споредба помеѓу Индустрија 4.0 и Индустрија 5.0 со цел прецизно да се карактеризираат двата концепта.

Клучни зборови: Индустрија 4.0; Индустрија 5.0; дигитализација; споредба

1. INTRODUCTION

The industrial revolution began in the early 1800s, transitioning agrarian societies to industrialization, driven by coal, water, and steam power. This period originated in Britain and spread globally, leading to the second industrial revolution in the late 1800s, characterized by mechanization and significant technological advancements. However, poor working conditions prompted the formation of labor unions and regulations. In the 1950s, the third industrial revolution began with the introduction of transistors and microprocessors, enabling automated production and improved working conditions. This era also brought challenges such as overcrowding and environmental issues. The ongoing fourth industrial revolution, known as Industry 4.0 (I4.0), emerged in 2011, focusing on digital transformation through technologies like IoT and CPS for automation and real-time optimization [1].

As the manufacturers struggle with implementing I4.0, discussions about the next industrial revolution, Industry 5.0 (I5.0), have already begun among industrialists and scholars. While I4.0 focuses on seamless data flow and optimization through digital machine connectivity, I5.0 is envi-

sioned to reintroduce human collaboration and emphasize sustainable manufacturing alongside product personalization [2]. Amidst the continued adoption of I4.0 across diverse sectors and the raising popularity of I5.0 (especially in the scientific circles), this study aims to perform comparative analysis between the two terms. The study doesn't aim to select a better concept because essentially I5.0 is an upgrade of I4.0, but rather characterize and define them. The following chapters include short literature review on both topics, in order to define what are the pillars and the theoretical foundations of both concepts. The final chapter includes a qualitative comparison using the Qualitative Comparative Analysis (QCA) method for more concise and structured comparison of the concepts according to selected criteria.

2. METHODOLOGY

The methodology for this paper involves an extensive literature review on the concepts of Industry 4.0 and Industry 5.0. The reviewed literature spans approximately the past three years, from 2020 to 2024, reflecting the rapid technological advancements in this period. The analysis is conducted using the Qualitative Comparative Analysis (QCA) method. QCA is a research method employed in social sciences to systematically compare multiple cases to study complex phenomena. It integrates qualitative and quantitative techniques to identify patterns and causal relationships within small to medium-sized datasets. The method comprises the following steps shown in Figure 1.

Fig. 1. Research methodology

3. DEFINITIONS

The term I4.0 refers to the fourth industrial revolution, which represents a technological alongside an economic, sociological, and strategic revolution [3]. The advanced technologies of I4.0, enable the collection, storage, analysis, and exchange of massive data between the human and machine in a fast an efficient way [4]. I4.0 enables the design of smart products and services with features such as more insight into customer requirements, better connectivity with customers, and real-time monitoring for better performance [5].

I4.0 is the current vision shaping the future of many industries by creating business models through cyber-physical systems (CPS) [6]. Nowadays, when thinking of I4.0 technologies, we mostly think of the enabling technologies of this paradigm. These technologies are also referred to as pillars of I4.0. In literature, pillars, and technologies of I4.0 usually mean the same.

One of the questions that emerged during the literature review for this paper is the dilemma of what is the definitive list of the digital technologies that should be considered as enablers of I4.0. The answer is that there is no such definitive list considering that it was discovered that many authors propose adding or subtracting pillars from the list depending on the use or simply on the time when the list was created considering the fast development of the new digital technologies. A short literature review was performed to define the list of I4.0 pillars by reviewing relevant sources on this topic [1, 7 – 10]. It is fair to conclude that most of the authors (although sometimes with different names, for example "autonomous robots" sometimes is referred just as "robots", or "collaborative robots" etc.) include the list of pillars shown in Figure 2.

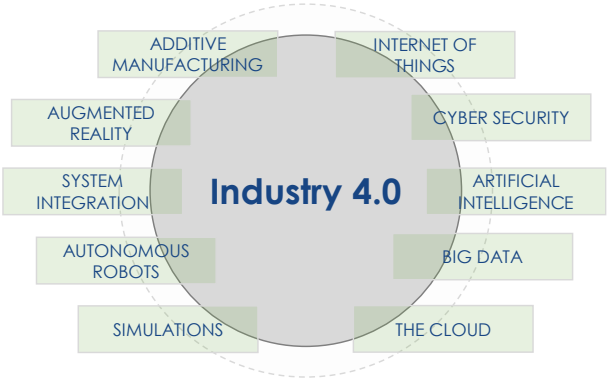

Fig. 2. Industry 4.0 pillars

While many authors and companies still struggle to implement most of the I4.0 pillars, and overall digital transformation [11], others are already researching the new emerging paradigm – I5.0 [12]. European commission defines I5.0 as a concept that complements the existing "Industry 4.0" approach by specifically putting research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry. This approach provides a vison of industry that aims beyond efficiency and productivity as the sole goals and reinforces the role and the contribution of industry to society. It places the wellbeing of the worker at the center of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet [13].

While much more uniform, here once again, authors argue regarding the pillars of I5.0 [14 –17]. The most common model that shows the pillars of I5.0 is shown in Figure 3.

Even though many authors are pushing this I5.0 paradigm, where most of them agree that I5.0 is an extension of I4.0 where the human factor is playing a key role, the popularity of the terms is significantly different. Simple trend analysis based on web searches per quartal (Q) in the specific year is shown in Figure 4. In the context of science, the analysis has shown that I4.0 has 92% more searches than I5.0 on daily basis.

The trend analysis is showing results from January 2021 to March 2024, and it can be concluded that, although I4.0 popularity is declining, it is still significantly bigger than the slowly increasing popularity of the I5.0 concept.

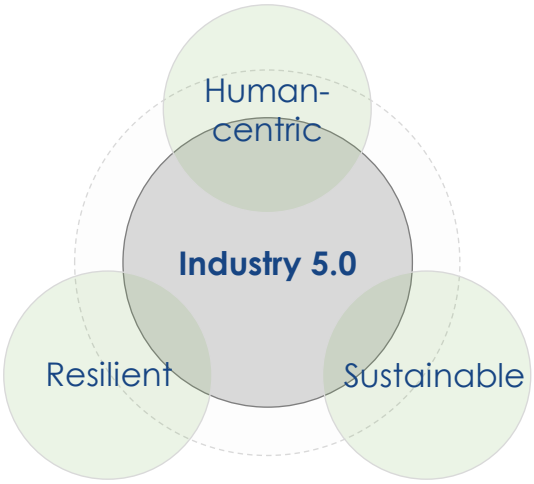

Fig. 3. Industry 5.0 pillars

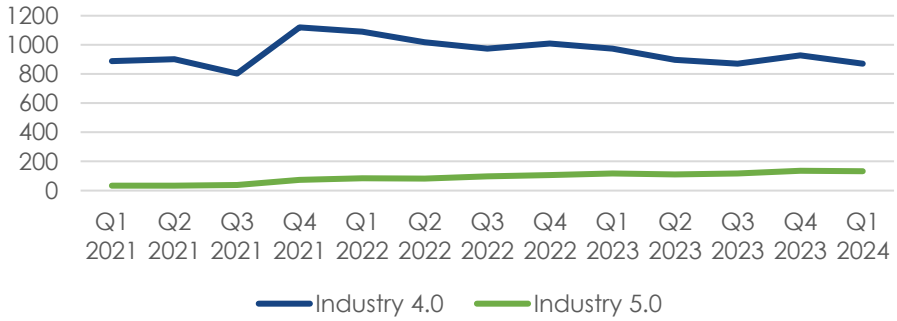

Fig. 4. Trend analysis: Industry 4.0 vs. Industry 5.0 (web searches)

4. QUALITATIVE COMPARATIVE ANALYSIS

For a more structured discussion, we will employ simplified Qualitative Comparative Analysis (QCA) method, as previously stated in the Methodology section of this paper.

4.1. *Case selection*

This specific case has been introduced in the preceding sections. The comparison will be conducted on two primary topics: **Industry 4.0** and **Industry 5.0**.

4.2. *Criteria identification and qualitative review*

Many authors already attempted to identify the commonalities and contrasts between the selected topics. When defining Industry 4.0 and Industry 5.0, and generally a technology disruption, in the literature there are several common factors that can describe these disruptions. According to different sources, authors have selected the most common criteria that will be utilized for the comparative analysis of the cases. The criteria are as following:

– Automation [18].

– Cultural readiness [11, 19].
– Customization & personalization [20].
– Data utilization & analytics [21].
– Economic impact [22, 23].
– Flexibility & adaptability [24].
– Human-centricity [25].
– High-tech products [26, 27].
– Social impact [25, 28].
– Sustainability & environment [28].
– Technology integration [24].

Qualitative review on each criterion was performed in order to find out more about the cases relation to each of these criteria. The results of the literature review that was conducted for both topics, with the key points is summarized in Table 1.

T a b l e 1

Cases research

Criteria	Industry 4.0	Industry 5.0
Focus	Smart mass production and digitalization.	Sustainability, human-centricity, and resilience
Automation	Connecting the machines in an integrated system.	Automation enhanced human work.
Cultural readiness	Weak.	Weaker than Industry 4.0.
Customization	Mass customization.	Hyper customization.
Data utilization & analytics	Efforts on data collection and utilization. Automated decision-making uses algorithms and analytics to optimize processes, while humans handle high-level decisions and strategic planning.	Same efforts towards data collection and utilization. Introduction of AI in decision making on the shopfloor, while humans again handle high-level decisions and strategic planning.
Economic impact	Investment in digital equipment.	Investment in strategy and goverment.
Flexibility & adaptability	Adaptive manufacturing processes through real-time data and connectivity, enabling systems to adjust to changing conditions based on automated feedback.	Extends the concept of adaptability by emphasizing the flexibility of human workers.
Human-centricity	Digitalization/automation of as much manual processes as possible. Human has main role in strategic planning, innovation, and making complex decisions.	Human role centers on collaboration with advanced technologies to enhance creativity, innovation, and personalized solution. Manufacturers make efforts to incorporate human as much as possible.
High-tech products	Not in the focus.	Customer experience is the most important.
Social impact	Indirectly affects but it is not in the focus.	Significant emphasis on social implications, aiming to improve societal well-being.
Sustainability & environment	Indirectly affects but it is not in the focus.	Core principle.
Technology integration	The goal is to create a highly connected and data-driven manufacturing environment for improved efficiency and decision-making. Central roles are taken by IoT, CPS, and data analytics.	Continues to leverage advanced technologies but with a greater emphasis on using technology to augment human capabilities. Human and machine collaboration, and AI are in the focus.

4.3. *Calibration*

To facilitate the comparison, in accordance with the method, values are assigned to each condition for Industry 4.0 and Industry 5.0, based on the literature and the authors' expertise. For simplicity, binary values will be used, where 1 indicates the presence and 0 indicates the absence of the condition. The result of the analysis is shown in Table 2. The cells where one case excels against the other one are marked with yellow.

T a b l e 2

Scoring of the cases against the criteria

Condition	Industry 4.0	Industry 5.0
Automation	1	1
Cultural readiness	1	0
Customization	0	1
Data utilization & analytics	1	1
Economic impact	1	1
Flexibility & adaptability	1	1
Human-centricity	0	1
High-tech products	0	1
Social impact	0	1
Sustainability & environment	0	1
Technology integration	1	1

4.4. *Interpretation*

For clarification, this analysis does not determine the superiority of one concept over the other, as the list of comparison criteria is not exhaustive and could encompass additional aspects where each concept may excel. This comparison aims to elucidate the primary characteristics and provide a detailed description of the concepts based on the available data.

Industry 4.0 is predominately characterized by constant strive to automate the existing processes, while utilizing as much technology as possible. According to the research, Industry 4.0 excels only according to the criteria regarding the cultural readiness. And even though research shows that usually companies score poorly in the readiness surveys [29], they seem to be much more ready for I4.0 concepts that are around for a decade now, rather than the new concepts related to I5.0 [19].

Industry 5.0 is predominantly characterized by customization, human-centricity, high-tech products and high social and environmental impact leading to more expressed support for the need of sustainability. Considering the fact that I5.0 excels in all categories (except one) as I4.0, it is safe to assume that this concept is containing all the previously mentioned positive aspects of I4.0 and it is a human-centred and environmentally cautious addition to what I4.0 essentially wants to achieve.

Industry 5.0 demonstrates better performance across multiple criteria, notably customization, human-centric design, high-technology products, social impact, and sustainability and environmental considerations. Conversely, Industry 4.0 shows a marked proficiency in the dimension of cultural readiness, which is expected considering the time that Industry 4.0 concept has been around. Both Industry 4.0 and Industry 5.0 share similar attributes regarding their emphasis on data utilization and analytics, economic impact, technology integration and flexibility.

5. CONCLUSIONS

Industry 4.0 (I4.0) represents a significant evolution in industrial practices, blending advanced technologies with economic, sociological, and strategic transformations. By leveraging the capabilities of cyber-physical systems, I4.0 facilitates the seamless integration of humans and machines, enabling efficient data exchange, real-time monitoring, and the creation of smart products and services tailored to customer needs. However, defining a definitive list of I4.0 enabling technologies remains challenging due to the continuous and rapid development of new digital innovations. While the industry struggles with the full implementation of I4.0, the emerging Industry 5.0 paradigm is gaining attention. I5.0 aims to transcend the goals of efficiency and productivity by focusing on sustainability, human-centric processes, and social responsibility. Despite the growing interest in I5.0, I4.0 continues to dominate in popularity and implementation readiness, reflecting its decade-long presence and the industry's familiarity with its principles.

This paper presented Qualitative Comparative Analysis (QCA) of Industry 4.0 and Industry 5.0 based on several selected criteria that were identified in the literature as the most usual factors to compare these technological shifts. Industry 5.0 excelled according to most of these criteria including customization, human centricity, high-tech products, social impact and sustainability & environment. On the other hand, Industry 4.0 excelled in the cultural readiness dimension. It is noticeable that Industry 4.0 and Industry 5.0 have similar characteristics when it comes to the focus in data utilization & analytics, economic impact, flexibility, etc.

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