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Industry 5.0: The Arising of a Concept

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Abstract

The march of industrial progress is marked by the appearance of disruptive technologies that originate revolutions with a significant social and economic impact. The last unfolding industrial revolution is known as Industry 4.0 ushering the emergence of smart factories using cyber-physical systems and IoT. In recent years, the term Industry 5.0 has appeared in several sources associated with different concepts. This lack of a clear definition, prompted us to do a bibliographic analysis on the arising of the expression "Industry 5.0" in the scientific literature. Most of the works associate it with a fifth industrial revolution, which will do what I4.0 did not achieve: promote a more just and sustainable society, in which there is a symbiotic/collaborative relationship between human and machine/robot. This set of values subscribe the European Union strategy and vision for the future of the industry but still lack a unifying idea that binds these values and technological solutions to characterize I5.0 as a truly industrial revolution.

Keywords: Literature Review; Industry 4.0; Industry 5.0; Operator 4.0.

1. Introduction

Throughout its history, humanity underwent many technological evolutions. These evolutions can be seen as transitions of state that tend to occur gradually. When a significant or disruptive change occurs, these transitions are designated as revolutions. These revolutions can take years or decades and do not always imply the annihilation of the previous state. Most of these revolutions were triggered by the emergence of new technologies, new ideas, or

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policies in a particular domain but their impact ends up being transversal. The industrial revolution is a good example of one of these great developments. It started in the second half of the 18th century and unfolded over the following decades. The introduction of the machine was the technological innovation that forced artisanal production techniques to change to mechanical ones. This disruption in production methods ended up having repercussions that also fractured the economy and the society [1].

This revolution, known as the First Industrial Revolution started in England triggered by the invention of the steam engine. The replacement of steam by electricity opened the doors for mass production. These innovations originated in Europe and the USA the Second Industrial Revolution during the second half of the 19th century. The Third Industrial Revolution was triggered by the invention of the Silicon Integrated Circuit in the second half of the 20th century. In the beginning of the second decade of the 21st century, the idea of the Fourth Industrial revolution arose, proposed not by historians or sociologists but by the politicians and technologist [1]. The concept of "Industry 4.0" was presented by the German government as a development program in 2011. Similar programs can be identified in other geo-graphical areas in and out of Europe: "new industrial France" in France, "Advanced Manufacturing Partnership Project" in the USA, "The Revival Strategy", in Japan and "Made in China 2025" in China. Their common goal is to push for the adoption of a new industrial paradigm that embraces a set of recent and future technology developments.

The scientific community embraced the term "Industry 4.0" (I4.0) to describe the fourth industrial revolution. With an annual average growth of published works (indexed in Scopus) of about 90%, we can consider that this revolution is still in progress holding a lot of potential to provide economic and social benefits.

Yet, in recent years, the expression Industry 5.0 (I5.0) has emerged in blogs [2], social networks [3], institutional research and innovation programs [4], and academic works [5–9]. At first glance, this term may lead us to think that it is associated with a new industrial revolution. This raises some questions: "Will we be facing two revolutions simultaneously?" and "If it is a new revolution, what is the associated disruptive technology?". The search for an answer in the literature revealed that the term "Industry 5.0" is associated with different concepts. This lack of agreement was the motivation for this work, that is, to understand the arising of the concept of I5.0.

The rest of the paper is structured as follows. Section 2 describes the methods used to assess our question. The results are presented on section 3 and discussed on section 4. In the last section, concluding remarks are presented.

2. Methods

To answer the research question, a systematic literature review was conducted. To assure rigor and replicability, the key steps of a systematic review process described by Littell et al. [10] and illustrated in Fig. 1 were followed.

Topic formulation: this work does not intend to be an exhaustive analysis of the literature produced around I5.0, but catch the main concepts associated with the expression "Industry 5.0" when it started being used by the scientific community. To achieve that goal, this study proposes to answer the following research question "How did the expression "Industry 5.0" arise in the peer-reviewed scientific literature?".

Study design: to find the initial concepts associated with the introduction of the expression, it was necessary to focus on the body of scientific literature, verify when the expression was introduced and identify the associated concepts. The Scopus database was selected as representative of the body of peer-reviewed literature and searched for documents containing "Industry 5.0" within the keywords field. The use of only this single keyword looks to focus the search on this particular expression and limiting the search only to the keywords intends to catch the author intention to connect the paper with the topic.

Sampling and Data collection: the databased was queried in March 2021 without limiting the year of publication or the journal. A collection of 37 papers in English was retrieved.

Data analysis: a descriptive analysis of each paper was conducted to summarize the novel concepts proposed in relation with I5.0. In addition, bibliometric approaches were used to identify the most relevant papers in the

collection, examining citation data and cross references over time, to highlight those that introduced each of the identified concepts. This bibliometric analysis used an R package, bibliometrix [11].

Reporting: The results from the previous step are presented next using narrative, tables, and a historiograph, generated with bibliometrix, of the most locally cited articles in the collection. Papers that are classified as non-relevant will not be discussed or referred.

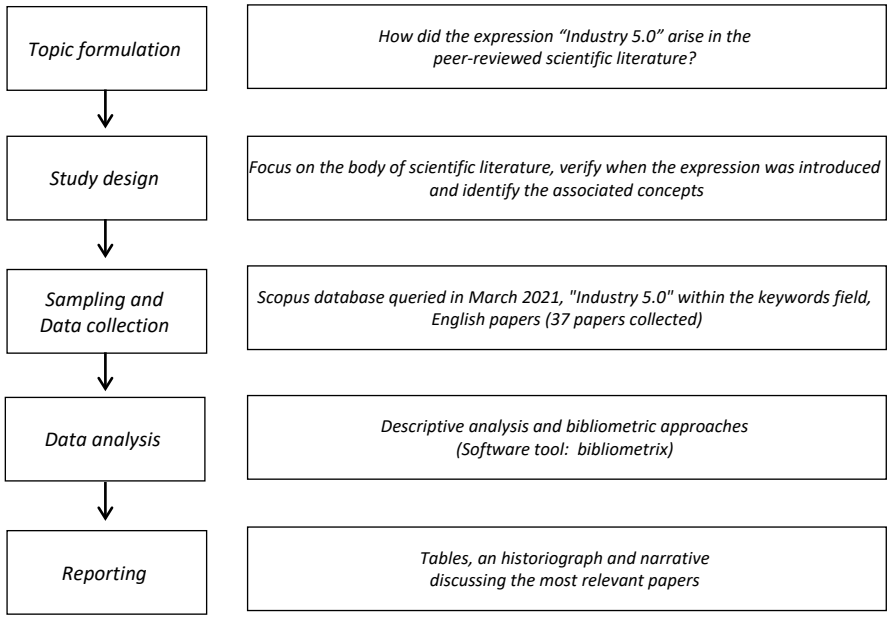

Fig. 1. The systematic literature review process, based on Littell et al. [10].

3. Results

The first fact that outstands from our results is that the first paper, in our collection, to use the expression "Industry 5.0" was the work of Sachsenmeier [8], in 2016.

An initial analytical approach guided us in the selection of the most important works in the collection. Table 1 shows the five most cited papers. Even if the reason for citation may not be associated with I5.0, it helps to classify the relevance of the papers.

Table 1. Title and publication year of the most cited papers of the collection

Cited Article Title	Authors (year)	Cited	Ref
Birth of Industry 5.0: Making Sense of Big Data with Artificial Intelligence, "the Internet of Things" and Next-Generation Technology Policy	Özdemir and Hekim (2018)	68	[5]
Industry 5.0—A Human-Centric Solution	Nahavandi (2019)	30	[6]
Industry 5.0 and Human-Robot Co-working	Demir et al. (2019)	18	[7]
Industry 5.0—The Relevance and Implications of Bionics and Synthetic Biology	Sachsenmeier (2016)	17	[8]
A Novel Intelligent Medical Decision Support Model Based on Soft Computing and IoT	Abdel-basset et al. (2020)	12	[9]

The relevance of the most cited articles is clarified with the historiograph shown in Fig. 2. The graph displays the collection articles along a timeline and connects the references to its sources. The historiograph reveals that four of the most cited works, are the main sources for the other articles in the collection.

Following the timeline, we summarize the concepts found in those articles and then consider other relevant concepts present in the bulk of the collection.

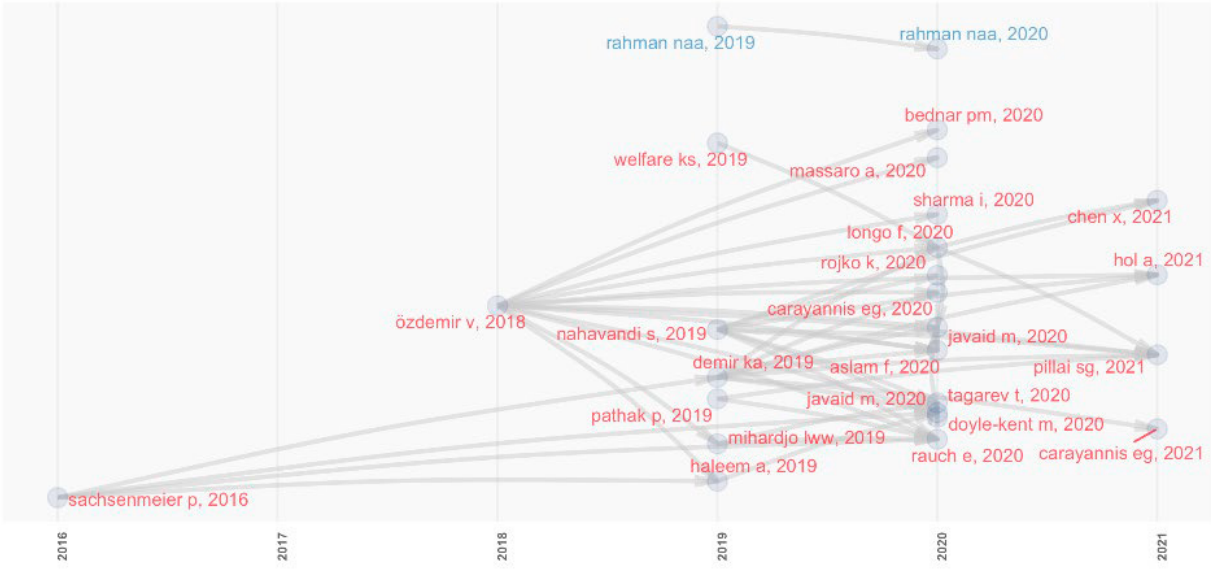

Fig. 2. Historiograph of the 25 most locally cited articles in the collection.

As mentioned, the first reference found that uses the term I5.0 is a work from Sachsenmeier [8]. This work explores “bionics as a conceptual precursor of synthetic biology”. It foresees bionics next frontiers as “the design of synthetic metabolisms that include artificial food chains and foods, and the bioengineering of raw materials”. I5.0 is introduced as a tectonic, disruptive, and even geostrategic shift to the industry and society foreshadowed by those technologies.

In [5], the most cited paper, I5.0 is proposed as an evolutionary, incremental advancement that builds on the concept and practices of I4.0. Its purpose is to build complex and hyper-connected digital networks without compromising long-term safety and sustainability. The author endorses the upgrade of automation systems with a built-in safe exit strategy that allows non-digital paths, control on the innovation development so it may reflect the expected returns and improvement in the research of social science and humanities so that emerging technologies may contribute to global wellbeing.

From the works presented in the Table 1, the first that connects I5.0 to a fifth industrial revolution is Demir [7]. The author states that scholars and futurists started the discussion of the concept, and two visions are emerging. One is “human-robot co-working”, where humans and robots will work whenever and wherever it is possible; and another is related to bioeconomy, as the use of biological resources in the industry to find a balance between ecology, industry, and economy. The author points out as reasons for this focus on mass production and the lack of environmental considerations of the actual I4.0 paradigm.

The work of Nahavandi [6] presents the concept of I5.0 as “autonomous manufacturing with human intelligence in and on the loop“. The author states that I4.0 is focused on process efficiency, forgetting the human factors. I5.0 corrects this because it will be a synergy between humans and autonomous machines; the human race will work alongside robots.

The last paper [9] of the 5 most cited ones only refers to I5.0 on the keywords and the conclusion. It only states that it is related to IoT.

Other works on the collection, mainly emphasize the relation human-machine in a similar way as described above: meshing machine intelligence with human intelligence, penetration of artificial intelligence into human life, human-cyber-physical system, or 'Age of Augmentation' (symbiosis of human and machine on work) [12–21]. Yet, some works even without citing any other on the collection, associate I5.0 with similar concepts or are vague in describing it [22–25].

It is noteworthy to mention another concept in the Japanese program "Society 5.0" presented in 2016, that aims to encourage the convergence between cyberspace and physical space in the society [15, 19, 24, 26–28].

4. Discussion

After distinguishing the concepts that are used to define I5.0, it seems appropriate to make a critical review of their application. Table 2 summarizes the initial concepts and vision related with the use of I5.0.

Table 2. Initial concepts related to the use of "Industry 5.0" as a keyword in the peer-reviewed literature.

A disruptive industrial and social scenario emerging from the development of bionics and synthetic biology, towards the design of synthetic metabolisms and bioengineering of raw materials	[8]
An upgrade of the I4.0 integrating safety and sustainability, contributing for the global wellbeing	[5]
An expected fifth revolution where humans return to industry and co-work with robots	[6, 7]

In 2016, Sachsenmeier [8], consider that the introduction of technology that allows for the design of synthetic metabolisms and the bioengineering of raw materials will have enormous impacts not only in industry but also in society. In fact, these technologies may have a similar impact as the firsts agricultural and industrial revolutions. For this reason, the use of the term I5.0 is adequate since the world would be facing a revolution.

To proceed with this discussion and discuss the following concepts, it is important to have a clear concept of what is considered as I4.0 by the research community. One of the most cited definitions is the one proposed by Hermann et al. [29]:

> *"Industry 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industry 4.0, Cyber-Physical Systems (CPS) monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things (IoT), CPSs communicate and cooperate with each other and humans in real-time. Via the Internet of Services (IoS), both internal and cross-organizational services are offered and utilized by participants of the value chain."*.

As stated, I4.0 is still a growing research topic. And like most engineering developments, it must overcome some barriers [30] and evolve over some iterations. The concept presented may appear to be reductive, but it is also very broad. Throughout its implementation, I4.0 can accommodate social considerations and concerns without losing its character.

Regarding the concept presented by [5], in 2018, and although the work does not refer the Japanese government literature, related with Society 5.0, similarities with this last concept can be found. The Japanese social strategy, presented between 2016 and 2017, states that Society 5.0 should be one that, *"through the high degree of merging between cyberspace and physical space, will be able to balance economic advancement with the resolution of social problems by providing goods and services that granularly address manifold latent needs regardless of locale, age, sex, or language."* [31]. The close relationship between I5.0 and Society 5.0 is also noticeable on many other references in papers of the collection [15, 19, 24, 26–28].

In 2018, it seemed hasty to "upgrade" to 5.0, to adjust some adverse effects detected in the present ongoing state. We agree with those who argue that the proposed state by [5] may be better referred to as Industry 4.0 Plus, Industry 4.0 Symmetrical, Industry 4.0-S. It may make sense that the fourth revolution ongoing could embrace the new ideals of society that were beginning to emerge across the world.

In 2016, Romero et al. published two papers [32, 33] whose titles appear to be self-explanatory: "Towards an operator 4.0 typology: A human-centric perspective on the fourth industrial revolution technologies" and "The

Operator 4.0: Human Cyber-Physical Systems & Adaptive Automation towards Human-Automation Symbiosis Work Systems". These works introduced a vision for the new types of interactions between operators and machines [32]:

> *"The vision of the Operator 4.0 aims to create trusting and interaction-based relationships between humans and machines, making possible for those smart factories to capitalize not only on smart machines' strengths and capabilities, but also empower their 'smart operators' with new skills and gadgets to fully capitalize on the opportunities being created by Industry 4.0 technologies. Hence, a socially sustainable factory within the Industry 4.0 framework is a workplace where work systems design and engineering uses collaborative robotics, kinematics, human-in-the-loop control systems, sensors, manipulation, navigation and adaptive automation to improve the knowledge and capabilities of operators."*

Since then, a considerable body of literature has started to be built around the "Operator 4.0" notion. The development of those works leads us to consider that I4.0 looks to adjust the human role in a socially sustainable way. The authors that associate the term I5.0 to an expected fifth revolution [6, 7], where humans return to industry and co-work with robots, do not refer to this concept of Operator 4.0 but could have used this framework. Actually, in our collection, only one work [21] references this topic. In our understanding, this distinctive I5.0 concept overlaps the Operator 4.0 concept presented earlier, under the umbrella of I4.0.

On July 2018, before [6, 7] we published, the European Economic and Social Committee promoted an event on Industry 5.0 [4], where we can identify similar concepts to the previously referred. The event goals were to "*shed light on how we can better integrate people into a society based more and more on digital technologies*", a similar approach to the concept of Society 5.0, stating that "*Industry 5.0 is focused on combining human beings' creativity and craftsmanship with the speed, productivity and consistency of robots. Industry 5.0 means to better appreciate the cooperation between robotics and human beings by combining their diverging strengths, in order to create a more inclusive and human-centred future."* This event had follow-ups, like two virtual workshops organized by Directorate "Prosperity" of DG Research and Innovation, on 2 and 9 July 2020, which gave rise to the publication of a brochure [34] in January 2021 entitled "Industry 5.0 - Towards a sustainable, human-centric and resilient European industry".

The debate promoted by the European Union (EU) on the shaping of Industry 5.0 is centered around values, such as human-centricity, ecology, and social benefits, close to the concepts proposed by [5–7], rather than on any disruptive technologies. It seems important to stand out that, unlike the Industry 4.0 presentation, the EU brochure [34] does not refer to Industry 5.0 as a fifth industrial revolution. However, we believe that that the close resemblance between the two terms (and acronyms) may lead to its widespread use in the scientific literature.

One last point worth mentioning is how most of the articles don't present new technologies but associate I5.0 with the ones already linked with I4.0 [35]. Many authors refer the use of IoT, Big Data, CPS, Augmented Reality, intelligent robotics and collaborative robots [26, 36–40], in such a way that it could be placed under the context of I4.0. In this sense, the disruptive nature of I5.0 is still an open issue in our understanding.

5. Conclusions

This work aims to understand how the expression "Industry 5.0" arose in the peer-reviewed scientific literature.

The expression was used first in 2016, on a paper that associates I5.0 with the emergence of disruptive technologies like bionics and synthetic biology. Yet, this is the least cited paper on the collection, although, it is the one that presented a concept that could be seen as a truly industrial revolution.

Most of the other works associate the expression I5.0 with a fifth industrial revolution, which will do what I4.0 did not achieve. One set of concepts, that share similar characteristics, is put forward: A revolution to promote a more just and sustainable society, in which there is a symbiotic/collaborative relationship between human and machine/robot. Like I4.0, the advent of governmental programs, the Society 5.0, by the Japanese government, and after the debates around the future of industry in EU, can explain the introduction and prevalence of this expression in the literature.

Yet, some of these concepts partially overlap ongoing research developments being made under I4.0, namely the Operator 4.0 framework. On the other hand, the disruptive nature of I5.0 is still an open issue since its core concepts are more clearly viewed as a set of values rather than a set of groundbreaking technologies.

This does not mean that future research developments could not help in defining a strong single idea that binds the identified values and technological solutions to characterize I5.0 as a truly industrial revolution with significant economic and social impact.

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