Exploring Research Trends in Healthcare 4.0

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Abstract. In recent years, healthcare is being challenged to deal with global aging, an increasing number of chronic patients, and growing demand for more personalized services. From this standpoint, it is comprehensible that health is longing for solutions to enhance its quality while reducing costs. In this light, the technological development brought by Industry 4.0 arises surrounded by high expectations of solving, or at least minimizing, some of the aforementioned questions. Therefore, this paper aims to investigate the current state of the health revolution, named Healthcare 4.0, and follows a systematic methodology to select the documents retrieved from Web of Science and Scopus. Firstly, keywords were chosen to execute the search in the scientific databases. Then, inclusion and exclusion criteria were used to define the final sample of 130 articles. Lastly, a bibliometric analysis was performed for a better understanding of the ongoing health revolution. With the assistance of the bibliometrix R-tool, graphics and statistics were designed in order to recognize publication patterns. It was concluded that, although Healthcare 4.0 is still a recent research topic, increasing attention is being given to it. The most influential authors and countries were also detected, enabling the recognition of India as the main reference in the subject. Moreover, the relevance of IEEE journals to Healthcare 4.0 was identified, and the importance of artificial intelligence was also revealed.

Keywords: Healthcare 4.0 · Health 4.0 · Industry 4.0 · Technology · Bibliometric analysis

1 Introduction

Healthcare is facing growing challenges in recent years. Threatened by the aging of the global population and the increasing number of chronic patients, the sector is in the wait for efficient solutions to better treat the ill and to enhance the management of their resources [1]. In this context, there is a high expectancy that with the use of technologies of Industry 4.0 in healthcare, such as the Internet of Things, cloud, big data, artificial intelligence, and robotics, some of these issues can be solved or, at least, minimized. It is expected that the costs of healthcare services will be diminished at the same time that the user experience is improved and the quality of care increased [2].

These advancements envisioned for healthcare are outcomes of the rapid technological development that the world is witnessing in the last few decades. In this regard, the already mentioned concept of "Industry 4.0" was first used in 2011 in a reference

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to the commitment of the German government to encourage new technologies and to provide a propitious scenario for the advancement of the local industry [3]. After that, the discussions about this theme only raised, and, in the World Economic Forum (WEF) in January 2016, the Fourth Industrial Revolution (FIR) was announced [4]. According to Professor Klaus Schwab, Founder and Executive Chairman of the WEF, the FIR is "characterized by a fusion of technologies that is blurring the lines between the physical, digital and biological spheres" [4]. In this light, it is predictable to imagine that the transformations derived from the revolution would not be restricted to the industrial area and that they could even reach the medical field.

Within this framework, the adaptation of Industry 4.0 principles, technologies, and applications in the healthcare area is named Healthcare 4.0, Health 4.0, or Healthcare Industry 4.0 [5]. It is already known that the neologism "4.0" has been widely used to indicate the last generation of technological and organizational innovations [6]. Other terms, such as E-health and smart health, are also used to refer to the current transformations that are taking place in the healthcare field, but none of them are clearly defined yet [7]. There is a lack of disseminated definitions in the literature. New terms are often introduced without providing a formal explanation [7].

Thus, there is a need for a better understanding of the ongoing health revolution. Therefore, the main goal of this paper is to provide an overall view of the current state of development of Healthcare 4.0, identifying the main participants and highlighting research trends. In addition, this study aims at providing the reader with a bibliometric review and an analysis of the evolution of existing literature.

The rest of the paper is arranged as follows. The next section presents the systematic review strategy used in the literature. A quantitative analysis is performed in Sect. 3. The study is concluded with Sect. 4.

2 Methods

The data collection was conducted to identify studies applied to Healthcare 4.0, since this area is extremely relevant and has enormous potential – in 2016, a poll conducted by the Economist Intelligence Unit pointed out that healthcare is the sector that will benefit the most from the Fourth Industrial Revolution [8].

The search protocol adopted in this research is summarized in Table 1. First, the electronic databases Web of Science and Scopus were selected with the intention to achieve maximum coverage of the management and engineering research literature. Second, two groups of keywords were defined. In the first group, the "healthcare 4.0" and its synonyms gathered in previous research [3, 9, 10] were selected. The second group involves "industry 4.0", "industrie 4.0", and equivalent terms also collected in the literature [11, 12]. It's noteworthy that "industrie 4.0" is how the new revolution was first mentioned in German, in 2011, and the term is still broadly used [13]. These strings were then combined with health-related terms in order to identify as many publications as possible associated with the topic. This second group of keywords was essential to reach a higher number of documents related to the theme of the research, considering that Healthcare 4.0 is a recent expression and not yet widely adopted.

Table 1. Search protocol

Data source:	Web of science and scopus
Search string:	(“health 4.0” OR “healthcare 4.0” OR “H4.0” OR “HC4.0” OR “Hospital 4.0”) OR ((“industry 4.0” OR “Industrie 4.0” OR “Fourth Industrial Revolution” OR “4th Industrial Revolution”) AND (“health” OR “healthcare” OR “hospital” OR “medic*”))
Search fields:	Title, abstract, and Keywords
Period:	From 2011 to December 31, 2020
Language:	English
Document:	Journal articles

In the first group of keywords, the terms were connected using the Boolean operator “OR”. In the second group, firstly, the synonyms of Industry 4.0 and the terms related to healthcare were separately connected using the Boolean operator “OR”. Then, these clusters were connected using the Boolean operator “AND”. Lastly, the first and the second groups of keywords were associated by the Boolean operator “OR”.

The search was performed in each database following the steps described next:

- Step 1: Search fields: title, abstract, or keywords of articles in the data sources.
- Step 2: Filter by year of publication: the search period ranges from 2011 to 2020, to enable an annual comparison.
- Step 3: Language: select only papers published in English.
- Step 4: Document types: refine the search to consider only journal articles, as they are usually peer-reviewed and, hence, considered more reliable. Then, both articles and reviews were selected.

The search was executed on April 1, 2021, and it resulted in an initial set of 757 publications - 370 articles were selected from Web of Science and 387 from Scopus. They were combined into a single database and the duplicates were removed using Mendeley. After that, the number of documents was reduced to 484.

The first screening, named Phase I, was done through the analysis of the title, keywords, and abstract of articles in the sample. The exclusion criteria in Table 2 were applied in the selection. Papers without abstract were preserved to allow a fair decision. This phase resulted in 165 documents and their full texts were, then, searched and downloaded (PDF files). In Phase II, the entire article was evaluated through the exclusion and inclusion criteria also specified in Table 2. After following the proposed steps, a total of 130 papers were included in the final sample for review. Subsequently, a quantitative analysis of Healthcare 4.0 studies was performed.

Table 2. Exclusion and inclusion criteria and number of occurrences

Phase	Description	Occurrences
Phase 1	E1: Healthcare 4.0, Industry 4.0, or Health is only cited or used as an example	167
	E2: The paper is not related to the scope of the research	152
Phase 2	E3: Full text could not be assessed	22
	E4: A quick mention to Healthcare 4.0	6
	E5: The paper is not related to the scope of the research	7
	I1: The paper focus on an application of Healthcare 4.0	54
	I2: The paper review or analyze Healthcare 4.0 or a topic of it	76

3 Quantitative Analysis

A bibliometric analysis is a quantitative approach for analyzing academic literature using bibliographies [14]. Through mathematical and statistical methods, scientific outputs can be measured, emerging topics can be identified, and research clusters can be found [15]. In this work, by investigating publication patterns, we aim to get insights into the current state of Healthcare 4.0.

The analysis was performed using bibliometrix R-Tool, a package developed by Massimo Aria and Corrado Cuccurullo from the University of Naples and University of Campania's Luigi Vanvitelli respectively [16]. This tool was chosen since it incorporates a great variety of different analyses, broader than the others considered [17].

After extracting the complete bibliography data of 130 publications from Scopus and Web of Science databases, the convert2df function was used in the R environment to create a unique data frame. Lastly, the merged document with the information from both databases was introduced in bibliometrix so that the analysis could be performed.

3.1 Year of Publication

Figure 1 (a) displays the distribution of scientific publications over time. Although Industry 4.0 was first introduced in 2011 [13], its applications in health were first mentioned in 2016. The oldest paper of the review sample, published in 2016, discusses if the healthcare sector is prepared to face the Fourth Industrial Revolution [8]. In the following year, studies about the theme were still scarce. The major shift happened in 2018, when the number of published articles increased 6 times. Since then, the quantity of documents related to the topic has been swiftly growing. This fact indicates that Healthcare 4.0 is still a recent research topic that is attracting increasing attention.

3.2 Geographical Distribution

The number of documents per country is illustrated in Fig. 1 (b). The publication activity of the countries about Healthcare 4.0 is as follows: India (23 documents), Italy (18

documents), South Korea (16 documents), United States (11 documents), United Kingdom (8 documents), Germany (7 documents), Spain (7 documents), South Africa (5 documents), Turkey (5 documents), Portugal (4 documents). These top ten countries contribute to 80% of total publications. The other 26 countries also in the image had 3 or fewer articles published. It is interesting to note that all continents were represented in the final set.

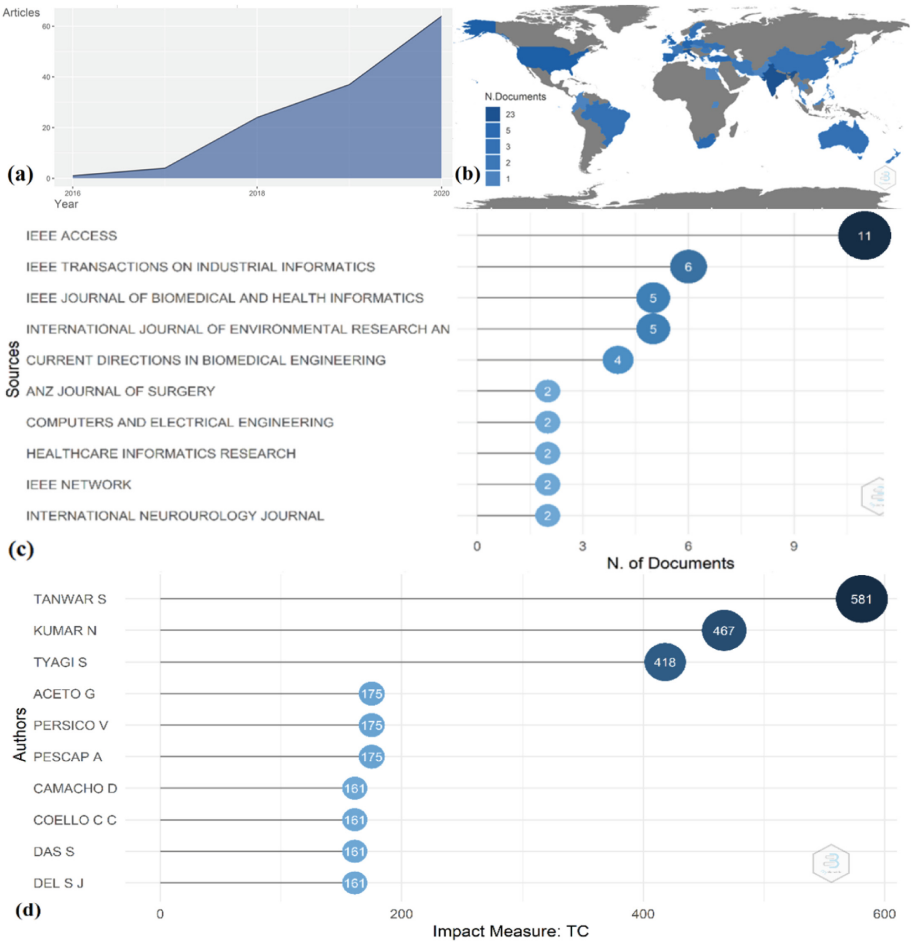

Fig. 1. **(a)** Annual scientific production **(b)** Countries scientific production **(c)** Most relevant sources **(d)** Author's impact

3.3 Leading Sources

The sample of 130 articles was published in 94 different sources and only five of them had more than two documents printed – IEEE Access (11 papers), IEEE Transactions on

Industrial Informatics (6 papers), IEEE Journal of Biomedical and Health Informatics (5 papers), International Journal of Environmental Research and Public Health (5 papers), and Current Directions in Biomedical Engineering (4 papers). Figure 1 (c) shows the ten journals with more papers retrieved from the literature review. Interestingly, the top three sources are from the IEEE association, whose focus is on the engineering, computing, and technology fields. Furthermore, it is worth noting that IEEE Access, the journal that appears most in the sample, has just started publishing about Healthcare 4.0 – two of its articles are from 2019 and nine from 2020.

3.4 Author's Impact

Bibliometrix provides four different measures to quantify the author's impact: h-index, its variants (g-index and m-index), and total citation. None of them is perfect. H-index is the most popular metric; however, it only considers the author's best publications, and low-quality work is not penalized – a fact that unintentionally is encouraging printing of immature work and micro-publication [18]. The total citation measure also has problems. It does not consider, for example, self-citations or negative ones [19].

Nevertheless, these metrics provide, if not a perfect, a good outlook on the author's performance. The total citation measure was chosen to evaluate the author's impact in this review and the results are displayed in Fig. 1 (d). Sudeep Tanwar was ranked number 1, with 581 citations, followed by Neeraj Kumar, with 467, and Sudhanshu Tyagi, with 418. All of them are from India and are also the three authors with more documents published; Tanwar and Kumar had 9 papers within the sample and Tyagi, 6 papers.

3.5 Keyword Analysis

Keywords frequency analysis is valuable, since these words depict the essence of articles in such a manner that, once the most used terms are identified, research hotspots and research cores in the field can be highlighted [20]. Figure 2 shows a word cloud with the high-frequency author's keywords and Table 3 presents the absolute occurrences of the ten most-cited names.

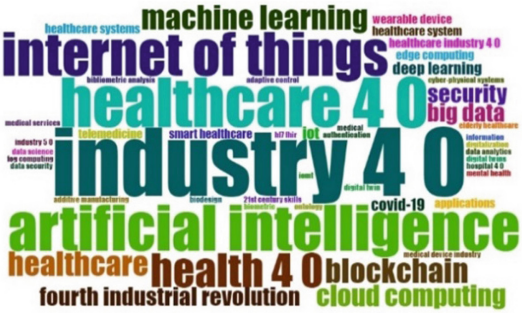

Fig. 2. Word cloud of high-frequency author keywords

Table 3. Most cited keywords

Words	Occurrences	Words	Occurrences
Industry 4.0	22	Blockchain	8
Healthcare 4.0	16	Healthcare	8
Artificial intelligence	15	Machine learning	8
Internet of things	14	Cloud computing	7
Health 4.0	11	Big data	6

A total of 534 different authors' keywords were collected from the sample, but only 24 of them were used more than two times. Industry 4.0 had the highest number of mentions, a predictable result due to the substantial connection between its technologies and Healthcare 4.0 along with the expansive dissemination of this concept. The same cannot be seen in the medical area. Both Healthcare 4.0 and Health 4.0 are in the top five of most cited words and Healthcare Industry 4.0 also appears in the nineteenth position. This fact illustrates the lack of a unique term and the need for a clear and widely adopted definition.

Through this study, it was also possible to identify the core technologies of Industry 4.0 applied in the healthcare area. Artificial intelligence is in the spotlight, being ranked as the third most cited keyword, and one of its branches, machine learning, was ranked eighth. Other technologies in the top ten are Internet of Things, blockchain, cloud computing, and big data. Interestingly, blockchain, which had no citations until 2018 and was mentioned only once in the following year, had a total of eight occurrences in 2020 – more than big data, for example.

4 Conclusion

This paper presented a bibliometric analysis dedicated to investigating the Healthcare 4.0 development. A replicable methodology was proposed to collect the data from both Scopus and Web of Science databases. Moreover, inclusion and exclusion criteria were applied to select the papers for the study, which resulted in a final sample of 130 journal articles. Then, the bibliometric analysis was performed with the assistance of the bibliometrix R-tool. Through the graphics and statistics provided by the package, it was possible to identify the current state of development of Healthcare 4.0. Research trends were also highlighted, and insights were pointed out to fulfill the aim of better understanding the ongoing healthcare revolution.

The analyses showed an increasing tendency in health-related studies since 2018 and that this field is swiftly drawing more attention. Moreover, it was seen that India is the main reference in the subject, since it is the country with the highest number of published articles and the three most impactful authors. It was also recognized the relevance of IEEE journals to Healthcare 4.0, although the association is not directly connected to the health area. Finally, the absence of a standardized and accepted concept was verified, along with the recognition of the most used technologies in the field.

However, there are still several open questions that need to be addressed to achieve the best of Healthcare 4.0. Security and privacy are huge concerns [21], and data ownership needs to be taken into consideration [22]. Furthermore, the lack of standardization and a regulatory structure are relevant questions that are not solved yet [23]. Lastly, ethics and legal issues must be addressed to allow the success of the healthcare revolution [24]. Through this review, a brief but enlightening view about the current state of Healthcare 4.0 was presented. It is expected that the findings of this paper assist and encourage further analysis of those interested in this research topic.

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