Systematic Review on the Theme of Sustainability in Industry 4.0

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Abstract

On the recent process of reflection on the values of a based-on consumption society, the analyst put in check the global capacity to attend the demand for capital goods and consumption combined with the simultaneous quality of life. Sustainability, in turn, as a field of disputes, seeks to extend practices in the industrial environment as a carrier of dimensions beyond the environmental, and also seeks to present new paradigms of production and consumption for the creation of new industrial value, seeking to mitigate impacts and externalities of the production process, through sustainable development. This article proposes to understand that interactions can be established between the fourth industrial revolution and the dimensions of sustainability, presenting their characteristics and their interconnections in the literature search. Through a systematic review of the literature, using the PRISMA method, the leading publications on the levels of integrated technologies of the so-called Industry 4.0 that are related to the dimensions of sustainability and its main trends in the academic field were analyzed.

Keywords: Industry 4.0; Sustainable development; Systematic literature review; PRISMA method.

1. Introduction

It is consensual that the current economic model today is in check. The global competitiveness in the productive sector needs constant changes since the environment is already showing signs of exhaustion. Within the actual production process in situ, companies are confronted by a variety of external factors, such as product range, shorter delivery times and product life cycles or high-quality requirements, leading to a complexity increased of the production process. An approach emerges and provides perspectives for establishing communication by sectors/machines in the production, through the internet, the so-called industry 4.0 (MAGDALENA; ERNST, 2016).

On the other hand, the capacity for constant renewal of the environment is already showing significant wear and tear, caused mainly by the commodification of ecosystems as providers of industrial inputs. Awareness is given in large part by the excessive search for advantages in the competitive market, and it is in this context that the so-called third and fourth industrial revolution appears as a milestone in the inexorable use of natural resources for their development (VEIGA, 2013). Since this awareness of the degradation of the environment and the decrease in the quality of life of the population measures are created to make the industrial process less aggressive.

In parallel with the discussion of industrial productive eco-efficiency, we have the organization of political-scientific reports that recommend, on a worldwide level, the internalization of residues inherent to the lifestyle based on consumption. Highlighting the "Limits to Growth" and the "Brundtland Report" (FILHO, 1993), which now consider intergenerational impacts and use terms such as Ecodevelopment and Sustainable Development, as alternatives to the so-called civilizational future. Also, the World Summits on Sustainable Development Rio 92, Rio +10, in Johannesburg and Rio +20, in Rio de Janeiro, which started to consider agendas with development objectives, also incorporating the intra-generational vision, with proposals aligned with the proposition of building paths for sustainability development considering dimensions that go beyond the environmental, economic and social tripod, starting to consider the political, cultural and territorial dimensions, in a context of interdependence (SACHS, 2008).

This discussion leads to new paradigms in the industry when it begins to adapt to the proposed models. In addition to environmental contributions, it represents a great opportunity to carry out sustainable industrial activities and create value in all dimensions of sustainability (STOCK; SELIGER, 2016). Among these opportunities, sustainable manufacturing presents the integration of processes and systems, making it possible to produce high-quality products and services using more sustainable resources, making it safer for employees, customers and surrounding communities (MACHADO; WINROTH; SILVA, 2019). The sustainable manufacturing using Industry 4.0 technologies is the principal choice left to manufacturers to help in the transition to a circular economy, in addition to positively influencing sustainable manufacturing resources (BAG; PRETORIUS, 2020).

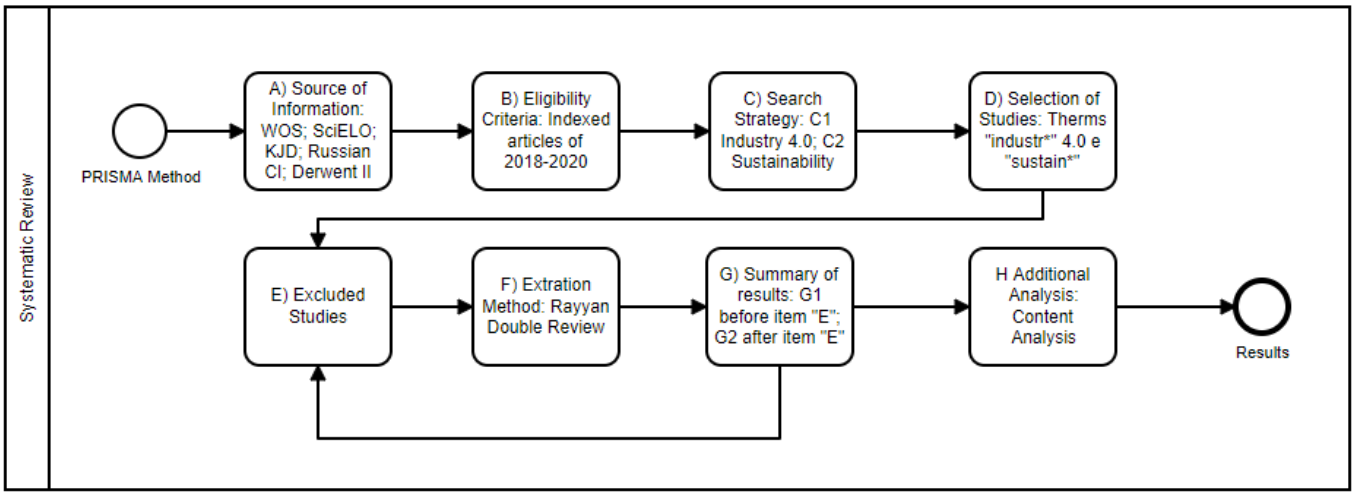
Given the need to change the paradigm of production and consumption, the technological advance proposed by the fourth industrial revolution and the need for sustainable actions, the problem posed is to highlight the trends in the debate that integrates sustainability with industry 4.0. In this context, the objective of this

article was to update, through a systematic literature review, the sustainability debate in industry 4.0, pointing out the trends, macro and micro categories that surround the theme.

2. Methodology

The systematic review of the literature from the categories industry 4.0 and sustainability, were adapted by the PRISMA Method (Preferred Reporting Items for Systematic reviews and Meta-Analyze) for studies of a socioeconomic nature. The PRISMA guidelines guide the objective of improving the quality of reporting of systematic review and meta-analysis data (BRASIL, 2012; MOHER et al., 2009) and its adaptation consisted of the following methodological path (FIGURE 1):

Figure 1- Adaptation of the PRISMA Method as a methodological pathway of bibliographic review



A. Source of Information:

a. Databases searched were Web of Science (WOS), SciELO Citation Index, KDJ, Russian Science Citation Index and Derwent Innovation Index;

B. Eligibility Criteria:

a. Articles Published in journals indexed between the years 2018 to 2020, including all countries with the publication of articles with title, abstract and keywords in English;

C. Search strategies:

c.1) Industry 4.0 category and

c.2) Sustainability category;

D. Selection of Studies:

a. search terms:

i. “industry 4.0”

ii. “sustainability”;

E. Excluded studies:

e.1) duplicate articles,

e.2) that do not deal with the two themes in the same article;

e.3) that do not treat Industry 4.0 and Sustainability as the main theme;

e.4) conference articles and books;

e.5) articles before 20xx.

F. Data Collection Protocols Extraction method:

a. Double Review using Rayyan application (OUZZANI et al., 2016);

G. Summary of Results:

g.1) bibliometry before item "E",

g.2) bibliometry after item "F";

H. Additional Analysis:

h.1) content analysis after item "F" (BARDIN, 1977),

h.2) definition of macro-categories, micro categories and trends of studies on Industry 4.0 and Sustainability.

The choice of the period 2018-2020 was made based on two recent studies that carry out articles until 2018, with an average of more than 30 citations per year. The first article portrays sustainability in industry 4.0 as a trend, with the study of 85 articles from 2012-2017, with a focus on the macro category technology, with main articles on the interaction between machine-human and human-machine (KAMBLE; GUNASEKARAN; GAWANKAR, 2018). The second, with 35 articles from 2008-2018, considers that the field of sustainability in industry 4.0 is not consolidated and guides trends in sustainability in industry 4.0 in micro categories such as business models, circular economy, value chains and policy agenda for sustainable development goals (MACHADO; WINROTH; SILVA, 2019). In this article, in turn, it sought to observe the emergence of new and / or maintenance of trends in the recent bibliography between 2018 and 2020.

3. Results

To reach the objective of updating the discussion on sustainability and industry 4.0, the results will be presented in 3 parts. The first consists of the multiple dimensions of sustainability and bring fundamental questions and historical references for understanding the emergence of sustainability as a new paradigm of production and consumption. The second part presents the industrial revolutions and the introduction of sustainability in the production process, with the priority for a reference until 2018. In the third part, finally, the trends of the intersection of these two categories are presented, focusing on the academic production of the last biennium.

3.1 The multiple dimensions of Sustainability

Since the mid-twentieth century, as a reflection of social dissatisfaction about the impacts of the contemporary way of life, they have appeared with exponential works on ethics, with emphasis on "A Sand County Almanac" (LEOPOLD, 1949) and public health issues, with emphasis on "Silent Spring" (CARSON; DARLING; DARLING, 1962). In 1968, after scientific discussions with researchers from different fields of knowledge, a political debate began at the global level, intending to unite the pro-environment discourse, which was consolidated at the Stockholm World Conference in 1972 (FILHO, 1993), which produces an important report called "Limits to Growth". In this report, Filho (1993) highlights that Ecodevelopment, as a development model, presupposed an intergenerational balance,

concerned with meeting its needs, the population and the economy of natural resources from an ecological perspective and also mentioned as the synchronic and diachronic solidarities.

Ahead, the concept of development model is improved to the idea of Sustainable Development (DS), which now comprises three dimensions, established in the midst of a debate that, according to Nascimento (2012), consists of the social, environmental and economic dimensions, known as the sustainability tripod. It should be noted that the method of only three dimensions did not cover all components in the civilization project; thus Filho (1993) includes two more dimensions, encompassing the concept of the dimensions of sustainability for also social, economic, ecological, spatial and cultural sustainability dimensions. Under the perspective that implies the scope of the dialogue on the limitation between socioeconomic and ecological, it is necessary to expand the dimensions both in perspective and in the future in social and pedagogical spheres. Therefore, only the three dimensions addressed are not able to measure eco-development. Nascimento (2012) states that the main problem of this is to focus only on these three, and not to address issues in the dimension of power, since political decisions influence and are connected to changes in production and consumption patterns. Thus, in addition to the five dimensions discussed above, the political factor will also be addressed, given the relevance of the theme.

To discuss Sustainable Development in a paradigm that enables dialogue with the State and its Public Policies, Sachs (2008) points out that sustainability is composed of eight dimensions, which, if worked integrally and synergistically, provide a significant step to think articulation of these agents and agencies. These dimensions are: economic, environmental, ecological, social, cultural, territorial, internal policy (so that projects are implemented) and foreign policy (based on equality of nations).

Since 2015, in this analysis of sustainability as multifactorial constraints, the UN has instituted 17 Sustainable Development Goals (SDGs) and 169 goals, integrating the 2030 agenda that presents proposals for improvement in public and private policies, for a higher quality of life in a sustainable manner for current and future generations. However, the Industrial sectors are more prone to negative sustainability (Kannan, Shankan and Kannan; 2020), so it is necessary to address strategies to promote and implement the practice of SD objectives in the industrial sector since two of the objectives (industry, innovation and infrastructure, and responsible consumption and production) are directly linked to Industry.

3.2 Industrial Revolutions and the introduction of Sustainability in the Productive Process

The concept of technical bases in carrying out human activities is also expanded, where this new process has revolutionized economic, social activities and human interaction with the environment. The Industrial Revolutions constituted this process, and it has been impacting (positively and negatively) all layers of sustainability, going from the first revolution, with the use of the first mechanizations, until the current one, bringing the Cyber-Physical system and enabling its interaction, with automation already installed at the factory, (MAGDALENA; ERNST, 2016).

After the three industrial revolutions, the fourth revolution, also known as Industry 4.0 or Advanced Manufacturing, presents itself as a new stage of development of industrial production in the world (VERMULM, 2018). The great advantage of Industry 4.0 on automation is the integration of technologies and artificial intelligence (VERMULM, 2018). In addition to the methods and technologies already used since the third revolution, more opportunities are still needed to ensure that information is being processed

and shared effectively and still simplifying by industry 4.0 on five levels, namely: level of intelligent connection, level of data conversion, cyber level, learning level, configuration level (MATOS; SCHEIDT, 2018). The same author also mentions the need to use tools to obtain the desired results, such as Big Data, Internet of Things (IoT), Cyber-Physical System, Cloud Computing and Security, helping in decision making, making it faster and more effective. These tools become pillars in technology and will transform the industrial process, making it more efficient (Silva et al. 2018), increasingly using renewable energies, as part of a supply, in addition to the power provided by the conventional electrical network (STOCK; SELIGER, 2016), and reducing carbon dioxide emissions (MAGDALENA; ERNST 2016).

In Germany, in addition to the good results obtained in the private sector, for being the pioneer in use, Industry 4.0 has prevailed, as one of the main sources of the economy in the country. The activities of the industrial sector represented in the economy a total of 20 to 24% of its Gross Written Value (VAB), and among the sectors that export, in Germany, the industry is the one that stands out the most, showing its high international superiority (SILVA et al. 2018). In Brazil, technology is still lagging in comparison with high powers, such as the United States and Germany. Ichi et al. (2018) state that industries in the national territory are still in the process of transition between Industry 2.0 and Industry 3.0, and that it is only through government investments that the implementation process may actually be accelerated. However, this investment should include, in addition to the market, education, to insert professionals in this new work scenario.

Leal et al. (2008) make explicit the environmental impacts that all industrial revolutions caused, since the concentration of pollution in places that had the growth in the population, and how these impacts stopped being local, to be planetary. However, Industry 4.0 brings with it the so-called integrated technology (MAGDALENA; ERNST, 2016), and the detailed information on the production process through it, improves not only the production chain but also improves energy use and energy efficiency (STOCK; SELIGER, 2016).

In a social projection, one of the key issues is the possibility of interaction between the fourth industrial revolution and society, so that the associated technologies help to repair the damage to society that the last three have caused (MORRAR, 2017), and in the ways creating values for people and the society of technologies that form the pillars of industry 4.0. This integration evolves ideas analyzed as opportunities to contribute to the so-called Super Intelligent Societies. Japan begins to integrate these technologies in the creation of Society 5.0 (FREITAS, 2018).

On a geographic scale, one of the benefits of Industry 4.0 is decentralization, avoiding overcrowding, one of the possibilities being the creation of new business models in less crowded places, since Industry 4.0 allows these models, prioritizing the development of small companies to supply their products and/or services (BEZERRA et al. 2018). Through these new business and investment models, decentralized industrialization and non-agricultural jobs in rural areas are possible. The Community Based Company (EBC) Bauana (Amazonas Community) is an example of the new business combined with artificial intelligence. Taking into account that both are linked to Industry 4.0, it is already present in remote places in the Amazon (through the encouragement of NGOs and private initiatives), in which actions such as the production of natural oils, entrepreneurship, higher education via the Internet favored by IoT and renewable energy (TRINDADE, 2019) are already a reality for residents of the region (Fundação Amazonas

Sustentável, 2020). This geographical impact caused by technologies originating from the fourth industrial revolution, in addition to being geographic, is still present in social, economic and environmental proportions.

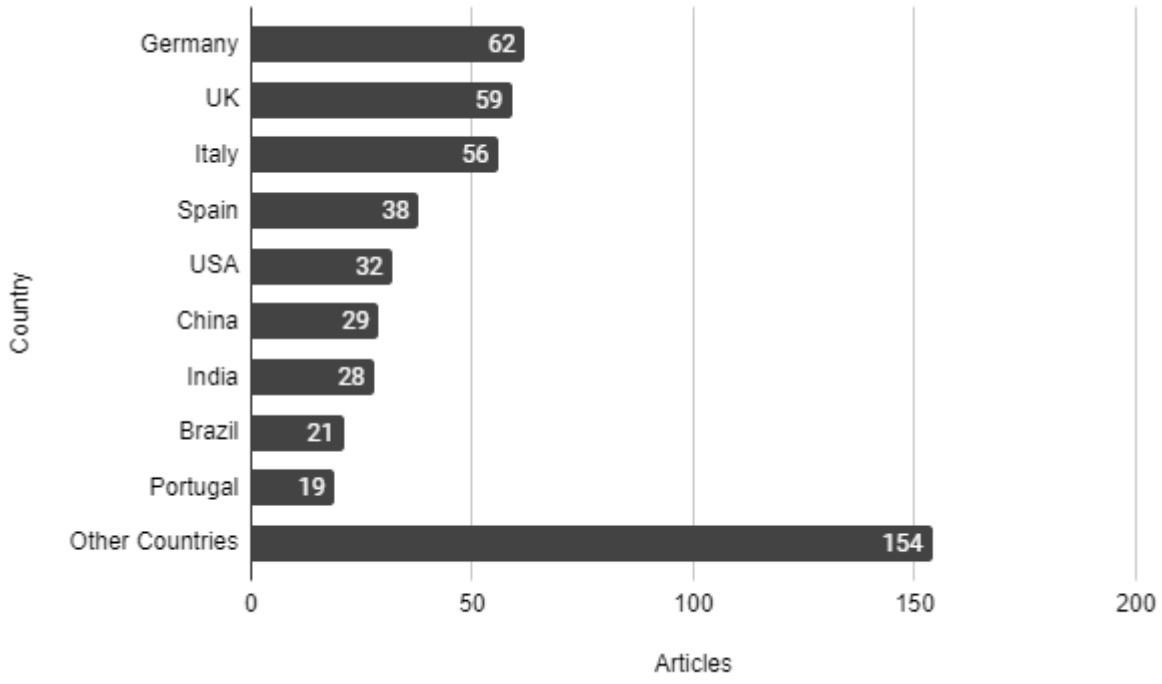
Integration is essential for the better quality of life of the population, and it is necessary, in addition to raising awareness of the correlation between these themes, the interest of public and private institutions in the implementation of Industry 4.0 in social, economic, political, cultural, geographical and in the reduction of environmental impacts.

Today we are already experiencing the Fourth Industrial Revolution and its massive economic potential. However, the question of the sustainability of this industrial development model is worrying, and it is necessary to adapt to this new industrial scenario, adjusting sustainability and its dimensions.

3.3 Sustainability Trends in Industry 4.0

In order to update the trends of the academic discussion about the theme of sustainability in industry 4.0, it was avoided categorizing previously as areas surrounding the two themes, in order to avoid pre-notions, and for the possibility of the emergence of new trends could arise. In this sense, a systematic review adopts the PRISMA method adapted with Content Analysis so that the categorization occurs after the application of the method, based on the pillars of Industry 4.0 and sustainability, analyzing its dimensions and interactions. The first bibliometric result is the concentration of articles produced by countries. In the first attempt, in part A, B, C and D of the methodology, a total of 498 articles were found between 2018 and 2020 (July 31), of which approximately 70% were concentrated in 9 countries (Figure 2), with a strong concentration thematic in European countries.

Figure 2- Concentration by countries responsible for 70% of article production (n = 498)

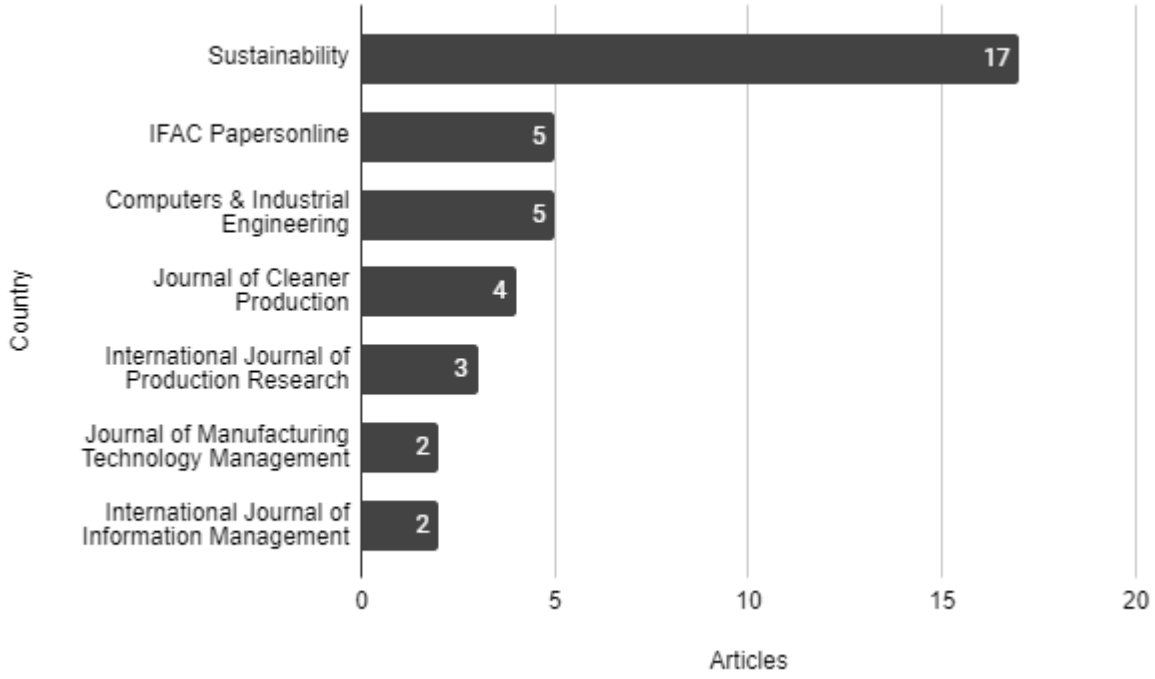


After reading the title, abstract and keywords of the 498 articles, applying the eligibility criteria indicated

in part E of the methodology, 258 articles were excluded in a double review, two of which were duplicates and 188, which dealt with only one of the two thematic, 47 articles of literature review on the themes and, finally, 69 articles excluded for not addressing these as the main theme. Of the remaining 192, 46 published in conference papers and 22 papers published in books and book chapters were still excluded. It was verified that of the rest, there were still 44 indexed articles dated before 2018.

In the end, after the procedures from A to F, there are 80 articles in indexed journals, which deal with the two themes as the main focus, updated between the years 2018-2020. Of these, seven (7) journals stand out, corresponding to 47.5% of all articles (Figure 3), with the rest of the articles being distributed in 42 other journals.

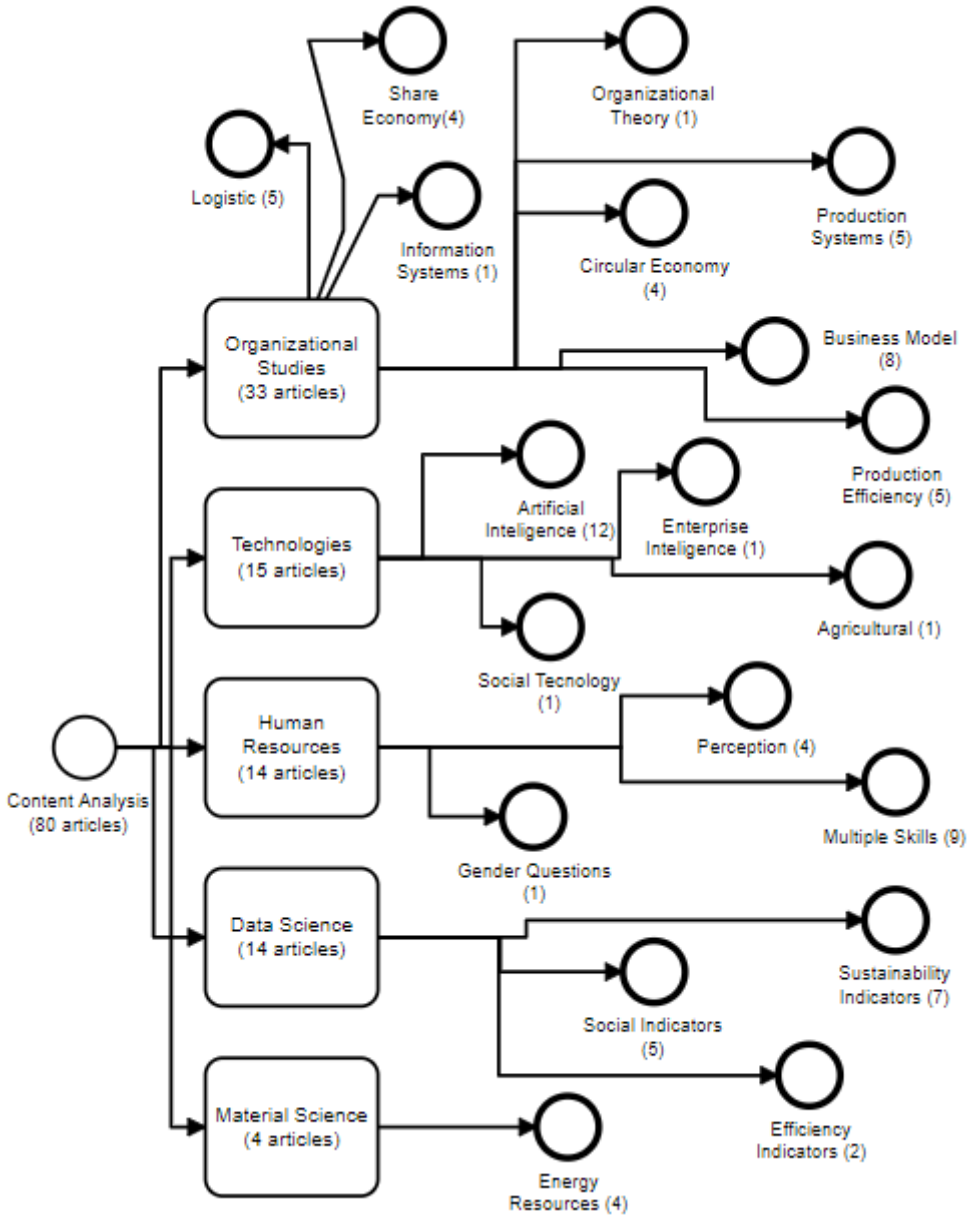
Figure 3- Concentration by journals (more than 2 articles) of article production (n = 38)



In all, in the period of 18 months, 575 citations were obtained, granting an average of 4.79 citations of articles per year.

The content analysis of these 80 articles consisted of three parts: 1) full reading and file; 2) categorization into macro-categories identifying the area of knowledge about each article; 3) distribution in micro categories with the main result of each of these areas. Regarding the macro-categories, five (5) major areas of knowledge were identified that produced recent articles with the debate on sustainability in industry 4.0: organizational studies, technology, human resources, data science and materials science (Figure 4) and 19 respective micro categories.

Figure 4- Flowchart of analysis of the macro and micro categories



In all, nine (9) articles concentrate approximately 45% of the total citations and point to the trend of scientific production on sustainability in industry 4.0, these concentrated in seven (7) micro categories and with representation in the five (5) macro categories.

3.3.1 Main trends in Organizational Studies

In Organizational Studies, two articles stand out, the first addressing the micro-business model category and the second on the circular economy. In a business model, the article talks about new business systems integrated with industry 4.0 and analyzes, considering the sustainable use of resources and supplies (Panetto et al., 2019). As for the circular economy, it analyzes cause and effect beyond the artificial intelligence of Industry 4.0 applied to the supply chain, showing results in a manufacturing, recycling, maintenance, useful life and sustainable supply chain ecosystem (Rajput and PrakashSingh, 2020).

3.3.2 Main Human Resources Trends

Two other articles point to trends in the volume of citations, the first highlighting multiple skills demonstrating how the sharing of knowledge and knowledge of employees (external and internal), human resource development can, through educational resources, help companies to adapt to Industry 4.0 (STACHOVÁ et al., 2019). Following, the second micro category on perception, addresses a sustainable city and the interaction with companies, obtaining results and the influence of the smart city in the qualification of employees for SMEs, sustainability (economy, environment, social) and recruitment of elderly and foreigners (Matt et al., 2019).

3.3.3 Main trends in Technology

In technology trends, both articles are related to artificial intelligence. The first presents ways and software to digitize the manufacturing of SMEs, through IT with management philosophies, in order to help in the transition to Industry 4.0 (Ghobakhloo and Fathi, 2019). The second, with a proposal to develop virtual education systems for students at universities (Salah et al., 2019).

3.3.4 Main trends in Data Science

In this category, both main articles studied deal with Social Indicators. The first proposes an analysis of environmental and social performance in consumer electronics companies in which there is a cooperation between R&D and eco-innovations, and their implication in economic performance (Tumelero, Sbragia, Evans, 2019), and the other analyzes the sustainable supply chain in health 4.0, proposing the glass structure as a channel that offers lighting resources, solar energy with photovoltaic panels and water management (Daú et al., 2019).

3.3.5 Main trends in Materials Science

The article studied on Materials Science deals in the micro category on energy resources, and studies the use of piezoelectric fibers and components, for generating electricity from natural and sustainable resources such as rain and wind (Chen et al., 2019).

4. Conclusion

There is a need for constant discussion based on Sustainability. As it is affected in its dimensions by Industry 4.0, from the analyzed bibliographies, it is possible to analyze the impacts suffered by previous revolutions, and the ways that the fourth revolution through its technology affects the environment, society, economy, politics, culture and geography.

To update the main trends arising from the integration between sustainability and industry 4.0, it was evidenced through analysis of the PRISMA method, 5 macro-categories of the 80 filtered forged articles from 498 surveyed initially. These macro-categories consist of organizational studies; technologies; human resources; data science; materials science. Of these macros, 19 micro categories are branched, of which, selected as having received the highest number of citations, and address sustainability and industry 4.0: business model; circular economy; multiple skills; perception; artificial intelligence; social indicators;

energy resources.

The debate integrated with the research shows the main trends in the academic world in the junction of the subject. This partial convergence is not new in academic publications, which allows for a greater explanation of the subject, and shows that people are attentive to the integration of concepts. The issues are connected, but there is still a strong misalignment between sustainable development and industrial development; however, their intrinsic alignment is vital for the smooth running of both Industry 4.0 and the dimensions of sustainability.

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