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Colombia in Factory 4.0: Bibliographical Analysis, Recommendations for Research Groups

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Abstract: In Germany the fourth industrial revolution has begun its course during these last years (Factory 4.0), it is characterized by smart factory creation and countries as South Korea, UK and China have shown interest in integrating different technologies as the Internet of Things (IoT), emerging Cyber-Physical Systems (CPS) and industrial network to factories and have achieved integrating smart production systems and total automation thereof. This synergy has allowed them attaining higher productivity and competitiveness levels in different sectors. This document describes the main progress made in Factory 4.0 during the last 3 years as documented in scientific literature, using the Scopus database. Bibliographical analysis is carried out by means of VosViewer finding the main lines of research implemented by leading countries. On the other hand, an analysis of the Colombian context is conducted and a set of recommendations are issued in order for them to be adopted by research groups and foster innovation in new technologies for the benefit of the country.

Key words: Factory 4.0, Internet of Things (IoT), CPS, smart agriculture, research groups, bibliographical

INTRODUCTION

Throughout human history, industry has lived many important changes in its productive process, strongly marked by historical events as the first industrial revolution took place from the second half of the 18 to the middle of the following century (1760-1860) (Wittenberg, 2016) and implied the inclusion of machines as the main workforce in manufacturing processes. The following event was the second industrial revolution in the middle of the 19th century which contributed with production lines in factories and the use of new energy based on electricity and oil. Industry continued progressing and so the third industrial revolution arose in the middle of 21th century and brought renewable energies, storage technology and smart electrical networks (Rifkins) to the table. As of today, we are talking about a fourth industrial revolution led by Germany, US, Italy, China, Japan and other global powers, Factory 4.0, the way this new revolution was named, aims at creating a synergy among different technologies in a fully automated factory using the Internet of Things (IoT) (Tapia, 2014).

Some South Korean, German, Chinese and British universities have issued multiple publications and studies concerning Factory 4.0, showing considerable interest in developing and applying the internet of things, industrial networks, cloud-assisted interactions, emerging cyber-physical systems, end-to-end engineering (Wang *et al*., 2016), among others. Developing these tools will allow modernizing all production systems by creating smart factories where all processes will be integrated, times reduced and costs diminished resulting in a substantial improvement of global economy. Research groups, graduate and undergraduate students and all people familiar with the topic have a big responsibility of researching and contributing with tools applicable to the Factory 4.0 concept. This is the reason for which this kind of research should be stimulated by universities, governments and by private companies interested in competitive advantage over other companies.

Taking global progress into account, it is clear that Colombia must focus its academic efforts in conducting technological production research in line with its economy and according to the future of the industry. This document contains a bibliographical analysis conducted by using VosViewer (Van Eck and Walman, 2010) allowing to identify Factory 4.0-related approaches that have been used for these last 3 years as well as the countries with the greatest number of publications with the aim of transferring this knowledge to Colombian research groups for the benefit of our economy.

MATERIALS AND METHODS

This bibliographical analysis was carried out in 5 steps. In the initial phase, a research was conducted on Scopus which was selected as it is the biggest source of articles and abstracts worldwide. Different research

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criteria were used for searching in the database also using a combination of the main terms related to Factory 4.0. This was done for the purpose of ensuring reliable and consistent sources. This being said, two document types were excluded: documents referring to ongoing events (conferences and courses) and documents that are being printed (in process of publication), the information comprised in the 3 years scope was also used for presenting updated results.

After using different combinations, we selected the following search criterion: (TITLE-ABS-KEY (Factory 4.0) OR TITLE-ABS -KEY (smart AND factory) AND TITLE-ABS-KEY (internet AND of AND things) AND (LIMIT-TO (Pub. year, 2018) Or Limit-To (Pub. year, 2017), Or Limit-To (Pub. year, 2016), Or Limit-To (Pub. year, 2015)) AND LIMIT-TO (DOCTYPE “ar”)) that filters articles containing the key words “Factory 4.0” or “Smart Factory” in their title, abstract and keywords and that are related to the internet of things in the time range going from 2015-2018.

The database resulting from the research on Scopus is input into VosViewer which determines most used terms and researchers with more publications. The software graphically presents data that are interpreted to get some conclusions. On the other hand, Scopus is equipped with a data analysis tool that provides statistical data about the countries with the greatest number of publications, document published per year and number of publications by institution which are presented by means of graphics and briefly analyzed. Finally, some documents were selected for the purpose of understanding the most relevant topics and issuing recommendations about the trends which Colombia should focus on.

RESULTS AND DISCUSSION

The database obtained from Scopus began by entering “Factory 4.0” as the only research criterion that found 589 documents, 245 of which were research articles, bearing in mind that Scopus only analyzes titles, abstracts and keywords. It was found that some researchers included the term in said fields, reason for which their articles appeared but when carrying out a review of the content not all of them developed the topic in the article. In accordance with the above, it was necessary to implement a limitation to the filter by increasing the number of criteria, combining keywords and using “Factory 4.0” as base as it is the topic of study (Table 1) with the aim of obtaining more relevant articles and a broader vision of Factory 4.0 trends as per different researchers.

Table 1: Scopus research criteria results

Concept	Total of documents	Number of articles	Colombian articles
Factory 4.0	589	245	2
Factory 4.0 and smart factory	310	123	1
Factory 4.0 and Internet of Things (IoT)	143	57	1
Factory 4.0 and Internet Industrial of Things (IIoT)	99	34	1
Factory 4.0 and Cyber Physical System (CPS)	172	62	1
Factory 4.0 and end to end engineering	8	3	0
Factory 4.0 and Industrial network	83	27	0
Factory 4.0 and flexible manufacturing system	39	16	0
Factory 4.0 and cloud assisted industrial wireless network	2	2	0
Factory 4.0 and big data	65	22	0
Factory 4.0 and robotics	105	45	0
Factory 4.0 or smart factory	1168	476	2
Factory 4.0 or smart factory and internet of things	272	92	1

In the process of the research, we decided to group “Factory 4.0”, “Smart Factory” and “Interest of Things” as it is the most accurate filter for developing the purpose of this research. This resulted in a set of articles proposing prototypes, applications, studies and analyses concerning new technologies. Scopus delivered 92 articles, 165 conference documents and 23 press articles. It is important to clarify that only research articles were taken into account as this kind of documents are backed by indexed scientific reviews allowing to ensure information reliability. Conducting an analysis on Table 1, it can be observed that Colombian participation to this academic effort focused on the future of the industrial sector is minimum. The contribution of aforesaid country, regardless of search criteria did not result in significant scientific production, reason for which this document shall make some recommendations for local research groups seeking to increase exploration of these current and future scientific topics by producing articles related to Factory 4.0.

During the article reading phase, the researcher determined a possible cause of deviation from the main topic as Scopus search tool does not make the difference between two or more words that compose a term. To the contrary, it separates them and carries out independent searches in the text, for example when entering “Smart Factory”, the search tool searches for the term “Smart” and then for the term “Factory”. This has had an impact on the review of some documents that do not contribute with relevant information for the purpose of this research.

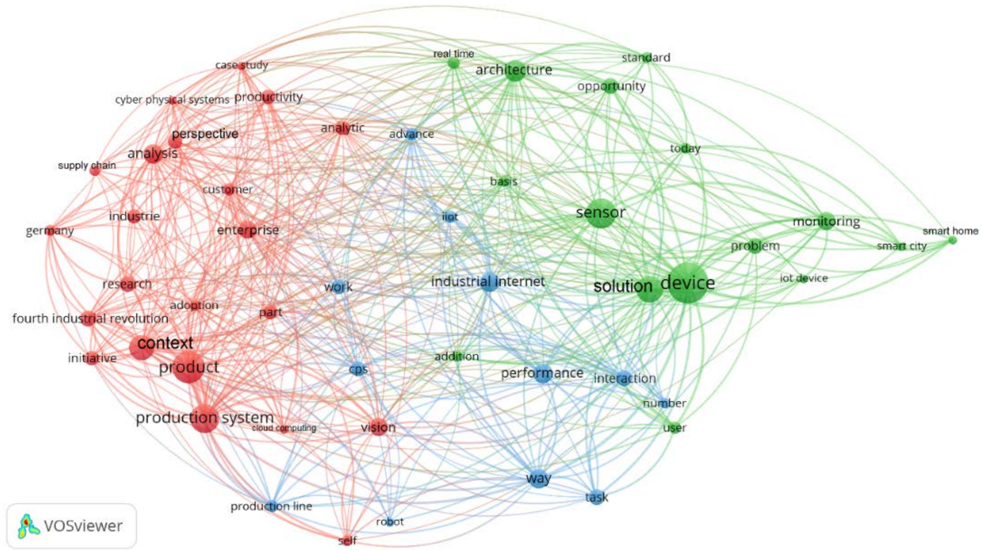

Fig. 1: Factory network 4.0, smart factory and IoT

The database obtained by applying the filter was analyzed in VosViewer that delivered the network presented in Fig. 1. It shows the terms with the greatest coincidence in titles, summary and keywords and on top of that the words highlighted with the same color are related according to the coincidence between terms and text sizedetermines a greatest number of repetitions in the search (Van Eck and Walman, 2010).

In Fig. 1 terms as industrial network, cloud computing, Internet of Things (IoT), Industrial Internet of Things (IIoT), emerging Cyber-Physical Systems (CPS) and smart manufacturing stand out which means that these concepts are the main research trends worldwide; followed by terms as real-time, productivity, production systems, monitoring, devices, sensors, smart houses and cities.

In the statistical data delivered by Scopus concerning the number of articles published per country (Fig. 2), it was observed that some world superpowers as South Korea, Germany, China and UK are filling the top positions with participations of 21.73, 18.47, 10.8 and 6.5%, respectively. This information confirms the high efficiency, competitiveness and application levels of automation, simulation, platforms, robotics and Flexible Manufacturing Systems (FMS) in said countries allowing them to have one among the best economies worldwide by means of efficient supply chain management. For the purpose of determining the research lines in these countries, each document is read and the most relevant and useful information is extracted, so, as to provide guidance to Colombian researchers.

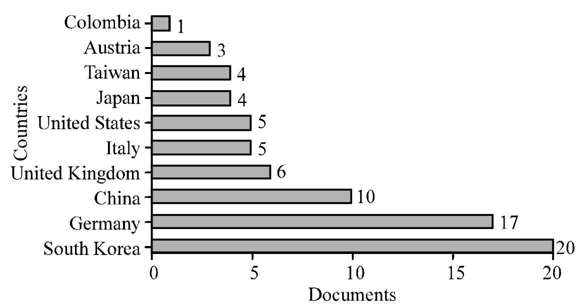

Fig. 2: Documents itemized by country of production

Influence of some world superpowers

South Korea: The first country in the Scopus publication ranking to date (Fig. 2) has produced more than 20 scientific productions oriented to IoT application in rotatory machines with cloud platforms (Jeong *et al.*, 2017a, b) in agricultural companies for ginseng selection processes using a network of cameras and algorithms determining ginseng size and weight this reducing operating costs (Jeong *et al.*, 2017a, b) in industries producing industrial vinyl film (Lee and Kim, 2016) in the automotive sector (Shin *et al.*, 2016) in injection molding companies (Lee and Kim, 2017) and in the industrial sector in general (Jeong *et al.*, 2018; Kim *et al.*, 2017), use of Factory 4.0 technology to carry out quality control (Lee and Kim, 2017), application and development of algorithms for CPS implementation (Jeong *et al.*, 2018) enabling to evaluate the performance of the supplying chain in real time (Lee *et al.*, 2017a, b; Kang *et al.*, 2016a, b).

Germany: This country fills the second place in the ranking with a total of 17 publications developing topics as the transition to the internet of things by using simulation (Teichert, 2016), application of Cyber-Physical Systems (CPS) (Mueller *et al*., 2017; Gronau, 2016; Wittenberg, 2016), integration of quick manufacturing to smart factory by integrated information and communication systems that allow attaining minimum waste levels (Sanders *et al*., 2016), review of the progress of greenhouse and of the installation of Controlled Environmental Agriculture technologies (CEA) (Shamshiri *et al*., 2018) as a response to the various problems that society is currently experiencing and the implementation of the FP7.

VISTRA (Gorecky *et al*., 2017) that aims at developing training systems by means of advanced virtual reality as Nintendo Wii and Microsoft Kinect, so, as to minimize staff exposure to the risk inherent to some operations.

China: It has published 10 articles focused on the integration of emerging Cyber-Physical Systems (CPS), smart hub as linking door for IoT devices (Lee *et al*., 2017), Cyber Physical Production Systems (CPPS), dynamic resource management based on IoT using efficient information exchange models and multi-agent technologies (Wan *et al*., 2018), requisites and key ideas for implementing smart ports and their equipment (gas container elevating machines and cranes) using IoT (Yang *et al*., 2018), use of the Colored Peri Network (CPN), so, as to carry out control and supervision actions in the context of manufacturing processes (Zhang *et al*., 2018), cloud-assisted interaction and implementation of industrial robots for the smart factory (Wang *et al*., 2017).

United Kingdom: During these 3 last years, the country has produced 6 articles with emphasis on smart manufacturing in the food industry of Festo (Andrew, 2017) and Andalucia (Spain) (Luque *et al*., 2017), carried out for the integration of Factory 4.0 in the supply chain using ERP, thus, allowing full control on production processes (Tjahjono *et al*., 2017) and on the areas of the company that would be greatly impacted by implementation (Majeed and Rupasinghe, 2017), social and technical requirements and the evaluation of techniques as quick manufacturing and 6 sigma for smart factory implementation (Davies *et al*., 2017).

A research was carried out in Scopus about the universities that are participating in knowledge construction. It was observed that the Korean Institute of Evaluation and Planning leads the ranking with a total of 5 publications, Chinese universities fill the second and third position, nonetheless, South Korea and Germany have a participation of 4 universities and South Korean universities have created different research groups as the I+D Smart Manufacturing Group exclusively dedicated to developing technologies for the industrial sector.

Analysis and recommendations for Colombia: The scarce participation of Colombia in Factory 4.0-related academic production is demonstrated by the scarce number of published documents, among them the article published by Universidad del Valle entitled "Development of 4.0 Industrial Applications" (Contreras *et al*., 2017) that aims at identifying the factors that must be taken into accountin updating industries and in the integration with Factory 4.0 by means of an architecture model named RAMI 4.0 that was presented by the Measurement and Automation Society VDI/VDE Control (GMA) in 2015 and enables the migration of the current industrial world to Factory 4.0.

It is understood that one among the possible reasons for such a scarce participation is linked to the research groups as they are not specifically focused on Factory 4.0-related lines. This is not the case of countries like South Korea that have constituted some groups like the I+D Smart Manufacturing Group exclusively dedicated to developing technologies for the industrial sector. For the purpose of verifying this statement, the topics on which the main universities of the country are focusing on have been verified. Factory 4.0-realted topics studied by local universities in accordance with the call for projects made by COLCIENCIAS (Administrative Department of Science, Technology and Innovation) in 2015 reveal interest in agroindustry development, automation, software and virtual reality development, the main groups are conducting research on Factory 4.0-related terms, nonetheless, said topics are not being associated to smart industry and progress, if any is not being documented by research articles as it was demonstrated by Scopus-delivered statistics.

According to the bibliographical review and research trends presented in Table 2, suggestions concerning which research lines should be taken into account by local research groups for developing Factory 4.0 topics are made hereunder.

Staff training based on virtual reality: The training process aims at transmitting specific knowledge related to the research of a group of people (Chiavenato, 2009) and is directly related to learning. During these last years, interest on virtual reality application in health sciences has increased, this technology can be applied to any learning context. Considering costs, space availability,

Table 2: Research group topics

Institution	Development topics research groups
National University of Colombia	Agricultural biotechnology, intelligent systems, software engineering, innovation in manufacturing processes, artificial life, technology in greenhouses, automation of machinery and processes, development of robotic solutions, development and industrial adaptation of manufacturing processes, automation for agro-industry, development of prototypes, industrial innovation, flexible manufacturing, reality and virtual manufacturing
University of Antioquia	Sustainable agro-environmental systems, agro-industry, computer intelligence and innovation in supply chains
University of the Valley	Artificial intelligence, intelligent systems, digital architectures, organizational and work psychology
University of the Andes	Human-machine interaction, supply chain and technology management, automation for production, software construction.
Pontifical Javeriana University	Automatic control of processes, intelligent systems, robotics, agro productive chains, use of erp, bioinspired systems, simulation, virtual reality, augmented reality, software engineering, computer security, internet of things, sensor networks.
District University Francisco Jose de Caldas	Architectures for power systems, artificial intelligence, industrial application networks, robotics, embedded systems, sustainable development, intelligent digital systems, virtual learning environments, software architecture, intelligent internet, computational intelligence
Pedagogical and Technological University of Colombia	Sustainable agrarian production, embedded systems development, software engineering, computational intelligence, internet of things, adaptive systems and simulation

staff, time and the degree of difficulty of the activities to be learned by researchers, it is suggested that research groups design prototypes based on virtual reality for tasks as machinery maintenance, assembling, installation and maintenance of energy networks, using technologies as holodesk, Oculus Rift, Kinect and Wii that provide the user with a complete interactive experience. It has been proven that the continuous implementation of staff training results in great benefits for companies as productivity improvement, production time reduction and time minimization (Diez and Abreu, 2009) reason for which the implementation of these technologies is of vital importance for companies.

Use of technology in industrial safety: As per the Colombian Insurers Association (FASECOLDA) a 7% accident rate was recorded in 2016 and the accident rate was even higher in sectors as manufacturing industry, mining, construction, agriculture and livestock (FASECOLDA). One of the reasons for these figures can be explained by the lack of technological tools facilitating industrial safety processes within companies. Therefore, it is suggested that research groups design sensors networks, vigilance systems and smart materials enabling us to monitor staff tasks and environmental conditions as the exposure to high noise levels, gas emissions and contact with dangerous substances, thus, minimizing accident probability and diseases at the workplace by preserving researcher's health. During the bibliographical review not a single document describing the safety conditions and factors to take into account in a smart factory was found and so, there is an opportunity for researchers to develop this research line.

Emerging Cyber-Physical Systems (CPS): CPS is one of the trends which the academic community is most interested into as they the base for turning conventional factories into smart ones, on the grounds of Factory 4.0. These technologies allow the smart connection of production systems operating in the physical structure or factory containing machines with IoT characteristics and storage systems. That is to say, CPS enable connection and feedback between the physical and cyber world having autonomous decision-making skills on heterogeneous problems and executing real-time actions to meet demand, minimize uncertainty and adjustment of production line performance indicators, machinery and quality control. Research groups developing these topics would provide the industrywith cloud-computing systems, more flexibility of offer and demand, so as to improve the systemic process and resource efficiency.

Internet of things (IoT): This research trend and object of study is strictly related with the topic above. IoT us a concept that has been built for 30 years enabling the connection of everyday life objects with the internet (Moreno *et al*., 2017), leaving closed circuits aside. It is suggested that researchers build knowledge on IoT and its application to the industrial sector, taking into account that this technology allows the interaction among devices facilitating communication and information sharing in order for CPS to make smart decisions based on the data transmitted by devices. Nonetheless, CPS and IoT development is limited by data transmission media (broad band) and 3G and 4G mobile networks, hence, research in 5G networks enabling reliability and support to the IoT is suggested. 5G is based on a software-defined architecture allowing dynamic programming.

Smart agriculture: Different countries have begun showing considerable progress in this field by using systems as Bitponics, Botanicalls and Koubachi that automate plant growth, human-plant communication channels and irrigation systems. In the case of Colombia, the agricultural potential is fundamental as the country relies on soils that are adequate for different crops. For this reason, research teams are recommended to work on the implementation of technological systems that can be used by smallholders, taking into account climate change affecting different regions of the country. We suggest the use of tools as IoT, RFID systems, sensor networks, drones, software, controllers and localization systems, so as to facilitate irrigation, pest monitoring (Ray, 2017), disease control, growth supervision, crop and livestock localization, the monitoring of environmental factors as temperature, moisture, water quality and rain probability. With the development of this sector, the improvement of competitiveness is sought as the sector represents 50% of total jobs in rural areas as per the statistical data delivered by the private council for competitiveness.

CONCLUSION

The publications produced by researchers of global superpowers demonstrate that Factory 4.0 seeks to integrate technologies allowing the existence of smart homes, factories and cars that facilitate people's lives. The internet of things, industrial networks, big data and CPS are the foundation for the invention and/or updating of new production systems based on the interaction between cloud and physical world enabling real-time decision-making for the supply chain using electronic devices as computers, mobiles and tablets.

Even if the country has different research groups studying Factory 4.0-related topics, a minimum participation to publications was demonstrated. It can be motivated by two possible causes, the first one is that the topics studied by said research groups are not associated to smart manufacturing and the second is that progress is not documented in scientific articles.

SUGGESTIONS

Taking into account the findings of the bibliographical review, 5 main research lines have been suggested: training based on virtual reality, use of technology in industrial safety, emerging cyber-physical system, internet of things and smart agriculture hoping that they will be pursued by research groups, so as to improve the competitiveness of the country in science, technology, innovation and research quality indicators concerning new technologies for the industry of the future.

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