Engineering research in Colombia

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With the beginning of a new decade, there are strong changes in many of the engineering paradigms, and of course, these changes will affect our society [1]. The emergence of disruptive technologies such as, e.g., artificial intelligence, additive manufacturing, augmented reality, pose a new scenario for engineering, where countries that adopt these new technologies in a timely manner will have an advantage. In this sense, it is important to assess the current state of research in the area of engineering in Colombia, and try to define a scenario where we can effectively face the new challenges that arise in this new industrial revolution.

Figure 1 shows the evolution of research in the subject area of Engineering for Latin America, according to Scopus records. Figure 1(a) shows the scientific production for each country vs. the number of publications indexed in Scopus [2] for the year 2018. Notice the proportional relationship between production and the number of journals, with Brazil being the first country in the region with 18 indexed journals and 10363 registered documents. Colombia ranks third, with a slightly higher proportion of journals, with 6 indexed journals, and a production of 2243 documents. Figure 1(b) shows the evolution of scientific production for the first four countries of the region between 1996 and 2018. Brazil has been the dominant country in the subject area of Engineering, with a total production of 115610 documents and an impact index $h = 205$. Colombia ranked fourth in the region until 2009, the year in which it surpassed Chile. Today Colombia holds third place, with a total production of 16678 documents and an index $h = 94$ for the same period. These results show a positive advance in research in the area of Engineering for the country, especially if we take into account that, according to World Bank data [3], Brazil invests 1.27% of its GDP in research and development, while Colombia remain fourth in this same group, with an investment of 0.24% of GDP.

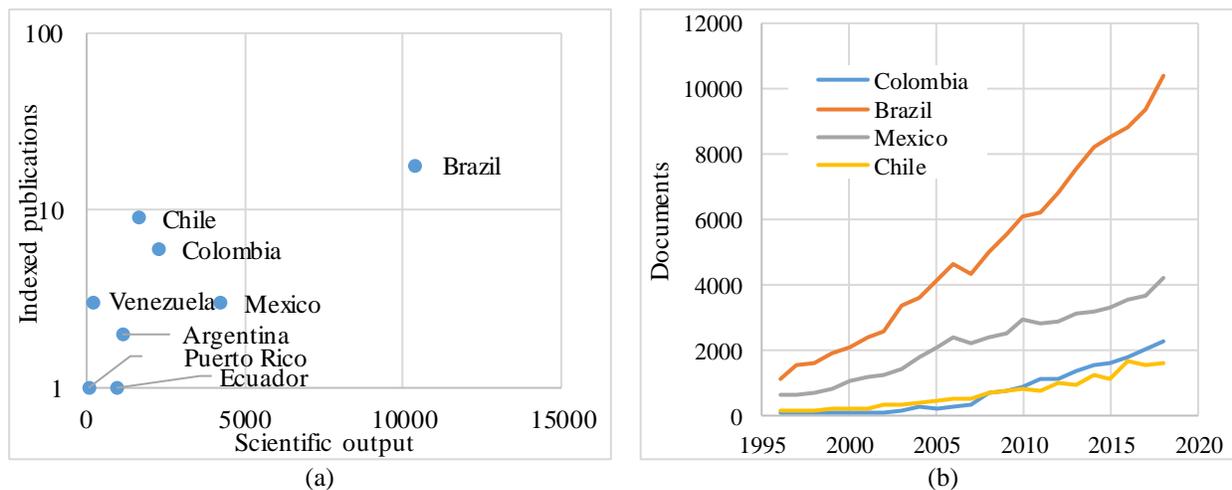(a)   (b)

Figure 1. Research output in the subject area of Engineering for Latin America (Scopus): (a) Scientific production vs. the number of publications indexed in Scopus, (b) Evolution of the number of documents per year for the first four countries of the region. Source: own elaboration.

The search in Scopus of the Colombian scientific production in the subject area of Engineering between the years 2015 and 2020 produced a total of 10125 documents [4]. The information was analyzed with the bibliometric tool VOSviewer [5]. The map with the co-occurrence of the keywords indexed by the database for the documents in the

Engineering area is shown in Figure 2. In the generated network there are three main research clusters: numerical methods, materials science, and energy.

In topics related to numerical methods, computational fluid mechanics and the finite element method stand out, which correspond to well-established research areas. However, there is also great growth in current topics such as machine learning and image processing. All these topics are framed within a new discipline that the National Science Foundation (NSF) has called Simulation-based Engineering Science (SBES), which is an interdisciplinary field that combines the knowledge of different traditional fields of engineering with the knowledge of fields such as computer science, mathematics and physics [6]. The SBES poses new challenges for solving increasingly complex problems, such as, e.g., multiscale modeling, the use of probabilistic approaches for the treatment of information, modeling of systems based on dynamic data, the use of information through the use of big data and high-performance computing (HPC). It should be noted that the SBES area has a differential advantage over other areas, and offers a growth opportunity for the country since it does not demand the high levels of investment required by the experimental areas.

In the cluster of materials sciences, we can find characterization techniques of mechanical properties and research aimed at the construction sector. In most countries, materials science has been a traditional research area. Today, the engineering trend focuses on the research and design of new materials, with unique properties such as, e.g., metamaterials, synthesized or formed on different scales thanks to nanofabrication [7], or materials for applications in areas such as health or energy.

On the other hand, global trends are observed in the third cluster, such as, for example, research aimed at sustainable development. In its vision for 2030, the United Nations has posed challenges around sustainable development aimed at proposing a transformation of society, environmental integrity, and economic viability. In this sense, the engineering trend towards research in areas such as energy efficiency, biomass and sustainable development can be observed.
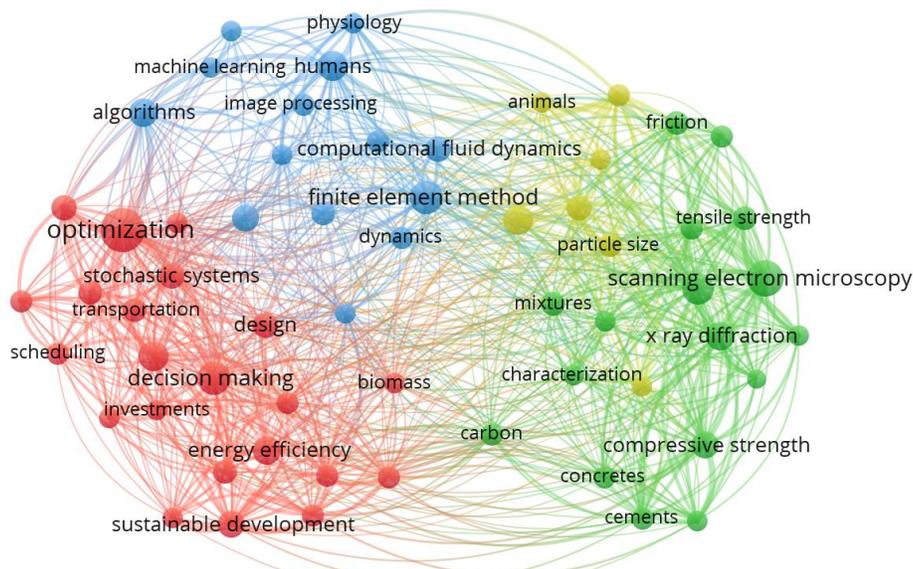

Figure 2. Map of co-occurrence of the keywords in scientific production for the Engineering area. Source: own elaboration.

Figure 3 shows the co-occurrence map for the keyword over time in the high impact scientific output in the subject area of Engineering, where the impact is measured from the number of citations of each document in the Scopus database. For the extraction of information, the period 2000-2020 has been considered, and the 2000 documents with the highest number of citations have been taken. This map offers an idea of the evolution of research topics in the country, showing new trends and more mature areas. The map shows the impact of the works developed in the area of structures: buckling, stability, columns, nonlinear analysis, etc., which is observed to take a longer period of permanence. The research in the area of materials sciences appears again, with a high impact, where we can observe topics of a long tradition in the country such as, e.g., the characterization and corrosion of materials, and more recent topics in nanotechnology and new materials such as graphene. Similarly, in the area of energy, there are topics of current growth such as biomass research, sustainability and energy efficiency.
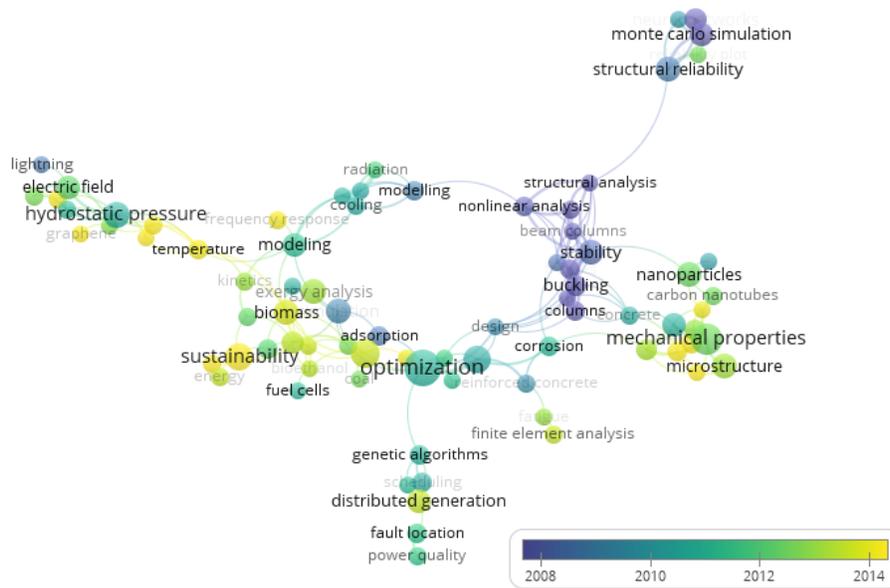
Figure 3. Map of co-occurrence of the keywords over time in the high impact scientific production for the Engineering area from 2000 to 2020. Source: own elaboration.

On the other hand, Figure 4 shows the collaboration network between countries obtained from the analysis of the bibliometric information of the documents in the subject area of Engineering. The collaboration with the United States, Spain, and Brazil stands out in the network. Likewise, the cluster of Latin American countries is observed within the network. There is also a wide network of countries on the map whose indirect collaborations result from participation in transnational networks and research groups, derived from the processes of globalization of science.
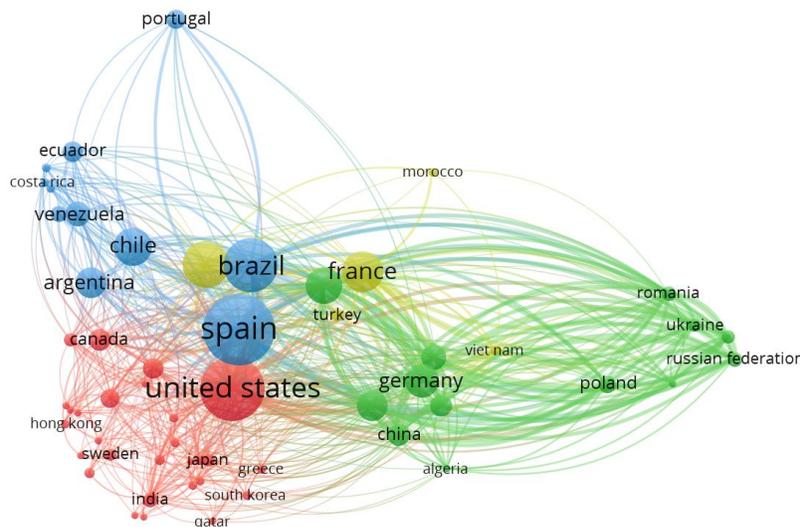

Figure 4. Bibliometric map of collaboration with other countries based on scientific production for the Engineering area in Colombia. Source: own elaboration.

In conclusion, there is a sustained growth of research output in the subject area of Engineering, supported by the internationalization of science, which with great effort, has tried to overcome the shortcomings associated with the lack of investment in science and technology in Colombia. Scientific production has increased in quantity, partly thanks to knowledge management based on academic capitalism [8], [9], and the challenge is now to improve the quality and impact of the research carried out. In this sense, it is important to direct investment policies in science and technology

towards applied research, in a way that allows us to address problems associated with the challenges in sustainable development and the transformation of society.

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