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CHARACTERIZATION OF THE TECHNOLOGICAL COOPERATION NETWORK IN INNOVATIONS BASED ON THE USE OF BIOPOLYMERS BY THE CIVIL CONSTRUCTION INDUSTRY THROUGH SOCIAL NETWORK ANALYSIS

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ABSTRACT

Biopolymers, replacing conventional polymers, have a wide range of applications in the field of civil engineering. The number of published patents related to the use of biopolymers by the civil construction industry is increasing, signaling the importance of intellectual property in these innovations. At the same time, economic globalization has made technological cooperation more relevant than ever, increasing the interest of the scientific community in the application of methods to investigate the collaborative networks involved in the development of technological innovations. Therefore, this study aims to identify the characteristics of the technological collaborative network on innovations in the use of biopolymers by the construction industry. The Social Network Analysis (SNA) method was used to identify and characterize the network based on data available on Espacenet. The study showed that in the technological cooperation network in question, the Kajima Road CO LTD and the Korea Advanced Institute of Science and Technology were the most notable organizations regarding patent applications, while the USA stood out as the country with the most connections and resources in the network.

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INTRODUCTION

In the last decades, massive population growth and migration to urban areas caused a large gap to form between the demand and supply of construction materials, which has led to the over consumption of natural resources and negative environmental impact (Arab *et al*. al., 2020). Therapid development of urban infrastructure has increased the demand for building materials, leading to negative impacts on the environment (Sathipran, 2021). Professionals in the construction industry have no alternative but to work on strategies to make the industry more sustainable. As such, environmental sustainability has been an increasingly present requirement in engineering projects and construction management (Zavadskas *et al*., 2021). Urbanization has caused an increase in the need for energy, consumption of non-renewable natural resources, and petroleum products.

As a result, the adoption of environmental and energy policies that support economic development without threatening the environment prompted the civil construction industry to seek out technological innovations that were part of its strategies to stay in business (Yilmaz; Bakis, 2015). Technological innovation related to energy saving, pollution prevention, waste recycling, green product design, and corporate environmental management has emerged as one of the key factors in achieving sustainable development goals (Yaya Li *et al*., 2021). Scientific research continually seeks to replace conventional polymers, produced from petroleum, which is a non-renewable source, with biopolymers, produced from renewable raw materials (Silva; Rabelo, 2017). Biopolymers have several possible applications in the field of civil engineering (Rashid, 2017) and numerous studies investigate the potential use of biopolymers in civil construction. Among them we can highlight research carried out by Kaddo(2020),

who analyzed the characteristics of the production and use of biodegradable biopolymers; Muguda *et al*. (2021), who investigated the potential use of biopolymers as stabilizers in building materials; Mendonça *et al*. (2021), who addressed the use of biopolymers to reduce the permeability of sandy soil; Barkhad *et al*. (2020), who developed new green polymer composites as building insulation material; and Arab *et al*. (2020), who investigated the development of a natural biocemented sandstone that can be used in the manufacture of green bricks. Other scientific works have discussed the use of biopolymers to improve soil strength and stabilization (Benzerara *et al*., 2021; Kang; Ko; Kang, 2021; Lee *et al*., 2021), and to manufacture sustainable concrete (Shanmugavel *et al*., 2020, Pinel *et al*., 2021, Tenório Filho *et al*., 2021). Beyond those studies, intellectual property and technological innovation can be identified through the increasing number of patent documents published in several countries on the use of biopolymers in civil construction. Among the various patents, we can cite WO2021240139A1, relating to an insulation product composed of fibers joined using one or more biopolymers; WO2021204918A1, for the manufacture of a drainage plate composed of biodegradable material; WO2019051212A1, referring to the creation of thermally insulating materials derived from cellulosic materials that can be composed of three main biopolymers, lignin, hemicellulose and cellulose; and WO2018142433A1, an invention applicable in the field of containment structures, where the cover for reinforced soil and excavation faces is manufactured from a material of natural origin, composite, biological or synthetic, like a biopolymer (Espacenet, 2022). At the same time, economic globalization has made technical cooperation more important than ever, promoting scientific and technological development between the parties (Dey *et al*., 2019). For technological and innovative knowledge to be acquired, organizations need to be involved in cooperation networks (Lee *et al*., 2021; Lubango, 2020). Therefore, the interest of the scientific community in the application of methods to investigate the collaborative networks involved in the development of technological innovations is increasing. One of such methods is Social Network Analysis (SNA), which allows the analysis of the relationship between the various actors and the characterization of the network through statistical calculations and graphics (Gomes; Porto; Costa, 2019). SNA can reveal hidden patterns that may not be captured by conventional qualitative and quantitative measures, helping scholars to visually understand network relationships, convey analysis results, and identify emerging trends in the development of new technologies (Pan *et al*., 2021). SNA makes use of mathematical methods and graph theories and is widely used to understand the interaction and connection between innovators (Yu *et al*., 2021). Patent documents are recognized as an important measure of innovation, as they contribute to investigations with valuable information and are available to the public (Gomes; Porto; Costa, 2019). For example, Dou and Bo (2022), using a patent database, used SNA to study how the adoption of building information modeling (BIM) evolved from 2011 to 2020. Barbastefano *et al*. (2021) carried out a study based on the filing of patents and presented an overview that gathered technical and market information on the wind energy industry through SNA methods, while Liu, Zhang and Zhang (2020) used the data of patent collaboration in China, from 2000 to 2018, to investigate university-industry cooperation networks in the Chinese system of technological innovation in the reduction of water pollution, among others. Thus, the present study aims to identify the characteristics of the technological collaborative network on innovations in the use of biopolymers by the civil construction industry.

MATERIAL AND METHODS

This study was based on data from patent documents on the use of biopolymers by the construction industry retrieved from the Espacenet database. The Espacenet database allows free access to 130 million patent documents worldwide (Espacenet, 2021). The descriptor "biopol*" was selected to developthe search strategy, which was performed in all text fields or names.

The search was restricted to patents from January 1, 2010, to January 31, 2022, in English and Portuguese. The codes of the International Patent Classification (CIP), or International Patent Classification (IPC), were also used in the search strategy, as they are more appropriate to the topic in question. According to the World Intellectual Property Organization (WIPO) database, the codes referring to Section E (Fixed Constructions) and Classes 01 to 06 (WIPO, 2022) were used, as listed below:

E01 – Construction of roads, railways or bridges;
E02 – Hydraulic Engineering; foundations; Soil stabilization;
E03 – Water supply; Sewerage;
E04 – Construction;
E05 – Locks; Window or door fittings; Safety;
E06 – Doors, windows, shutters or roller blinds in general; Stairs.

The search in the Espacenet database was performed using the string "biopol*" AND pd = "2010,20220131" AND (cl any "E01" OR cl any "E02" OR cl any "E03" OR cl any " E04" OR cl any "E05" OR cl any "E06"). Patent documents contain relevant information such as technology field, applicant, and priority. Statistics and analysis of data contained in published patent documents allow access to important information or knowledge (Liu; Zhang; Zhang, 2020), such as inventor, applicant, patent classification codes, claims, etc. (Ji *et al*., 2020). The patent is an effective indicatorof the level of technological innovation (Leng*et al*., 2021). Patent data provides relevant information about innovation and the collaborative network formed by different institutions (Yu *et al*., 2022). After establishing the technological production databases, the analysis and evaluation of cooperation were carried out using the statistical technique of Social Network Analysis (SNA). The information relevant to the patents was exported to Microsoft Excel® spreadsheets for further data analysis with the help of the Gephi® software, which is a tool that allows the structuring, visualization, and analysis of collaborative networks. According to Leme *et al*. (2020), SNA is a graphical statistical technique that allows forquick visualization and interpretation of associations between multiple variables. The SNA method is characterized by listing a set of nodes (or actors), and edges (or relationships) between them (Wasserman; Faust, 1994, Bordin; Gonçalves; Todesco, 2014). SNA can describe how nodes connect, directly and indirectly, in qualitative and quantitative terms (Liu; Zhang; Zhang, 2020). The visual analysis of SNA reflects the structure and attributes of the interactional relationships between the nodes (Shiyu *et al*., 2020). The SNA metrics used in the research were betweenness centrality, which verifies the number of times a member acts as a link between two other nodes (Shiyu *et al*., 2020) and evaluates the relationships between an actor and other two actors in the network, measuring the ability of actors to control the flow of resources (Liu *et al*., 2021); degree centrality, which reveals how many and which actors are connected to the same node in the network (Pan *et al*., 2021); and modularity, which allows the identification of cooperation clusters (Blondel *et al*., 2008).

RESULTS AND DISCUSSION

The search carried out in the Espacenet database resulted in 306 published patent documents related to the use of biopolymer technology in civil construction. Data referring to technological production identified in the documents is presented in Table 1. The data in Table 1 shows that, between 2000 and 2022, the number of actors involved in the publication of documents related to technological innovations on the use of biopolymers in civil construction was quite substantial, as was the number of patents published. The annual evolution of the number of patents in that period is shown in Figure 1. The time series shows that the number of patent publications grew over time, albeit irregularly. The annual evolution of patent publications supports the use of biopolymers by the civil construction industry as technological innovation, as evidenced by the increase in numbers of patents published from 2007 onwards, which points towards a growing awareness of the importance of intellectual property.

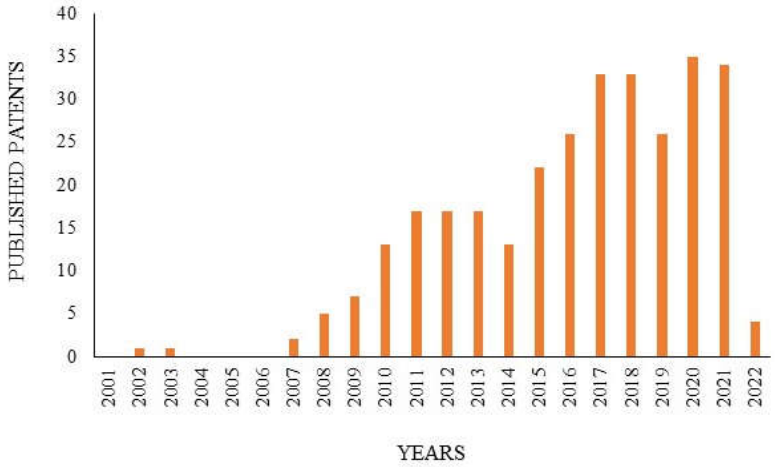
Table 1. Technologicalproduction

Database	Numberofinventors	Numberofapplicants	Numberof countries	Numberofpatents
Espacenet	665	288	34	306

Table 2 . Degree centrality and betweenness centrality of patent applicants

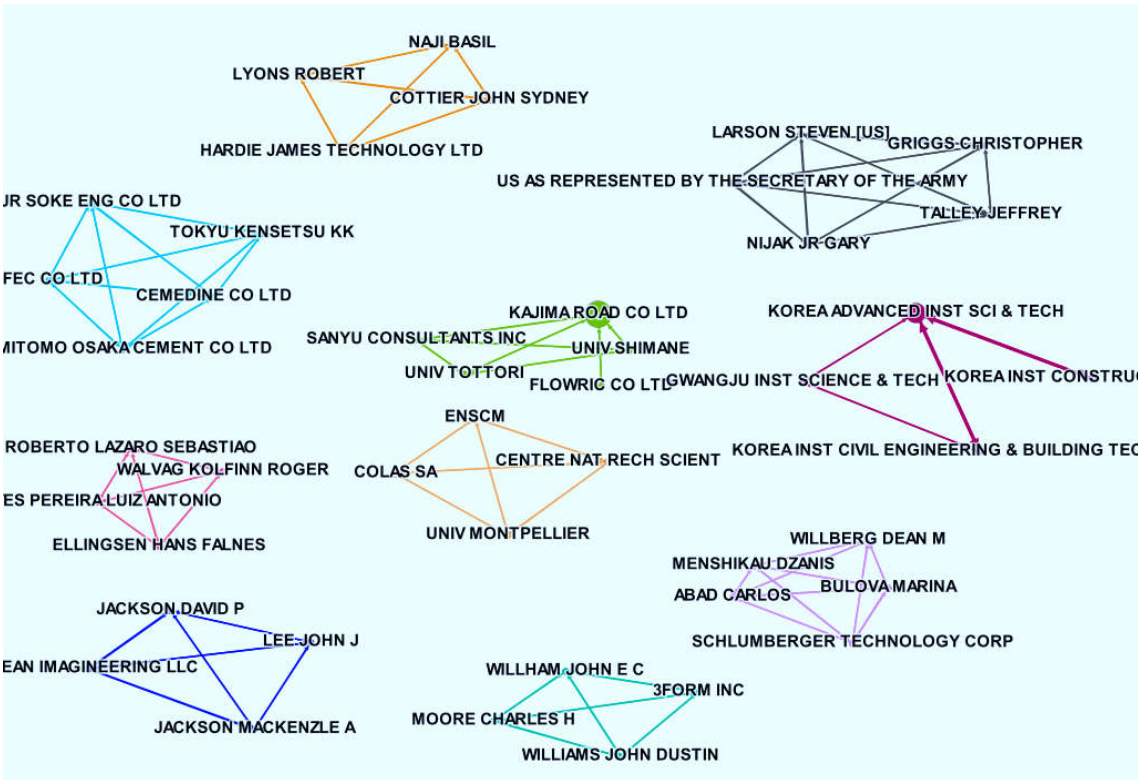
Authors	Degree centrality	Betweenness centrality
Kajima Road CO LTD	8	6
Korea Advanced Institute of Science and Technology	6	4
CQR CO LTD	4	2
Kang Eun Chang	3	1

Source: The authors (2022).



Source: Created by the authors, with data from Espacenet (2022).

Figure 1. Annual evolution of technological production



Source: The authors (2022).

Figure 2. Network formed by patent applicants

Source: The authors (2022)

Figure 3. Network formed by the countries involved in the collaborative network of technological production

Table 3. Degree centrality and betweennesscentralities of the countries

Authors	Degree centrality	Betweenness centrality
United States	10	16
Australia	4	0
Ireland	4	0
Belarus	4	0
Russia	4	0
France	2	0
Japan	2	0
Netherlands	2	0
Switzerland	2	0
Germany	2	0

Source: The authors (2022).

The drop in the number of publications in 2022 is due to the survey only accounting for the first month of this year. The analysis of the technological production network was carried out using the SNA method, built from patent documents, where nodes represent patent applicants and countries that are part of the network, and the lines represent relationships between the actors. Table 2 indicates the degree centrality and betweenness centrality of the patent applicants most relevant in the technological cooperation network. The data in Table 2 shows that the two most prominent patent applicants in the network are Kajima Road CO LTD and the Korea Advanced Institute of Science and Technology (KAIST), with betweenness centrality of 6 and 4, respectively. Those results indicate that they control the flow of information and resources and are the most influential claimants within the subgroups they belong to, with Kajima Road CO LTD having grade 8 centrality and KAIST having grade 6 centrality. Betweenness centrality indicates the number of times an actor connects to two other actors in the network, and degree centrality indicates those actors who have more ties to other actors, and consequently may have alternative ways of satisfying their needs, which makes them less dependent. A greater number of links translates to access to more resources of the network as a whole (Hanneman; Riddle, 2020). These metrics reveal the dispersion of the network as few applicants could be measured for them. The patents deposited by the leading organizations refer to technological innovations involving the use of biopolymers in methods of stabilization, reinforcement, and improvement of the soil, improvement of erosion resistance, in the covering of slopes, composites used in the manufacture of concrete, building blocks, in dam surface coating, among others. The patent documents reveal that authors Ilhan Chang, Gye-Chun Cho, Moonkyung Chung, Jooyoung Im and Yeong-Man Kwon, who represent research institutions in the cluster led by the KAIST, also participated as inventors of a few technological innovations for which already published patents were requested by KAIST and by the Korea Institute of Civil Engineering and Building Technology. According to the values of betweenness centrality, both the aforementioned authors, except for Moonkyung Chung, and the research institutions stood out as the most important in the study. Author Joon Gu Kang, from the Korea Institute of Civil Engineering and Building Technology, in partnership with Woochul Kang, from the same institution, and Dongwoo Ko, from Kyungsung University, published the scientific article "Erosion resistance performance of surface-reinforced levels using novel biopolymers investigated via real-scale overtopping experiments", in 2021. Joon Gu Kang, alongside Hong Kyu Ahn and Sang Hoon Lee, also participated as an inventor of the technological innovation entitled "River bank shore erosion prevention structure using coated biopolymer porous on concrete block and construction method therefor", applied fora patent by the Korea Institute of Civil Engineering and Building Technology and published on November 19, 2020. Figure 2, produced from modularity, presents the network formed by patent applicants for technological innovations based on the use of biopolymers in civil construction. The identification of communities in a network, modularity, allows the network to be explored more effectively (KAMIŃSK *et al*., 2019). Figure 2 presents the main collaborative subgroups formed by patent applicants, where the largest nodes indicate the most important actors in the network, Kajima Road CO LTD and the Korea Advanced Institute of Science and Technology (KAIST), supporting the evidence already found based on the data in Table 2. In the technological cooperation network, several applicants had the same or very close degree centrality values within the same cluster, indicating that these subgroups were not so relevant within the network (Leng *et al*., 2021). Data extracted from patent documents indicated that, of the 306 published patents, only 60 technological innovations were developed in partnership between organizations. Figure 3, based on degree centrality, allows the visualization of the collaborative network of the different countries involved in the technological production of the innovation considered here.

In Figure 3, the countries are represented by the nodes, and the links between them in relation to technological production are represented by the lines, which allows us to visualize the most prominent countries in the collaborative network of technological production on the innovation in question and to verify that they are in different continents. The countries are: the United States of America, Australia, Ireland, Belarus, Russia, France, Japan, the Netherlands, Switzerland, and Germany, with the USA being represented by the largest node, indicating a greater degree centrality and, therefore, greater relevance within this cooperation network. In a collaborative network, the greater the degree centrality and the betweenness centrality of an actor, the greater its control over the other actors (Lee *et al*., 2021, Rossoni; Guarido Filho, 2009). These observations are supported by the data presented in Table 3, which shows the degree centrality and the betweenness centrality of these countries. The data in Table 3 indicates the dispersion of the network, as only the USA presented a betweenness centrality score above zero. The country stood out in the technological cooperation network, with a degree centrality of 10 and a much higher value of betweenness centrality than the other countries. In a collaborative network, the role an actor plays depends on its location in the network, with a more centralized position indicating a more important role in the development of the network. Actors with high degree centrality values play a more active role in the network and are assumed to have access to more resources, making them more independent and more powerful. Likewise, the actors with the higher betweenness centrality values, that is, those who operate faster through shorter paths between other actors, are considered more powerful and more influential over the others (Hulst, 2009). Technological innovations were developed by the USA in partnership with Germany, Australia, Belarus, France, Ireland, and Russia. According to Gordon (2019), the USA is the country that most encourages the development and protection of intellectual property rights, with public policies aimed at innovation, prompting innovative processes, promoting innovative companies, and promoting actions to strengthen cooperation between different agents of the economy in the face of public or private demands. As a result, the country has fostered a productive sector with a greater capacity to generate and disseminate new knowledge. In addition, in 2012, the country adopted the "National Bioeconomy Blueprint", which describes five strategic objectives to fully utilize the potential of its bioeconomy, promoting the introduction of new materials on the market, including biodegradable plastics derived from renewable biomass (White House, 2012). The Global Innovation Index 2021 ranked the USA as the country with the fifth-highest performance in technological innovation, after its government budg *et al* locations for R&D grew by 10% in 2020 (WIPO, 2022).

CONCLUSION

The Social Network Analysis found an insignificant technological cooperation network, in which there were no partnerships between countries for most of the published patents. Only 2% of authors who research the topic also appeared as inventors in published patent documents. In this network, the USA stood out as the country with the greatest influence and with greater control over the flow of resources in relation to other countries. There was no evidence of any Brazilian inventor or organization participatingin the application for patents connected to the technological innovation discussed here. Despite the significant number of patent applications by South Korea, the technological innovations generated by the country didnot involve organizations from other countries. Considering that technological productions increase over time, it is recommended that new analyses be carried out from 2022 onwards to identify the behavior of technological cooperation networks on the innovation in question from this point forward.

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