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Scientific Cooperation Network in Innovations in the use of Biopolymers in Civil Construction

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Abstract*—The search for innovative technologies for the use of materials from renewable resources to replace conventional materials has been a constant issue. The number of scientific publications on the use of biopolymers by the civil construction industry has grown over time. On the other hand, cooperation in the exchange of knowledge and resources has been found as one of the solutions to overcome relevant obstacles to scientific and technological development. Thus, the objective of this study was to identify and characterize the cooperation network formed between the various actors involved in scientific production on innovations based on the use of biopolymers by the civil construction industry. The cooperation network was characterized using the Social Network Analysis method (SNA). The study showed that in the scientific cooperation network, Ilhan Chang and Michael D. Lepech appear as the most important authors, the Korea Advanced Institute of Science and Technology, the Universiti Teknologi Malaysia and Stanford University are the strongest organizations, and Malaysia is the country with the most significant participation.*

I. INTRODUCTION

The accumulation of residue associated with the intense use of natural resources and the increase in production activities harm the environment. The rational use of natural resources, the destination adequate treatment of waste and protection of the environment have been constant concerns (Kaddo, 2020). Furthermore, the consumption of fossil materials has had negative impacts on the environment, resulting in the need to produce energy from renewable sources (Ibarra et al., 201). Thus, the civil construction industry has faced several challenges related to growing

concerns about the environment and has been dedicated to searching for technological innovations that will replace petroleum products, making the industry and its final products more sustainable (Jędrzejczak*et al.*, 2021).

There has been a very significant increase in scientific research on new functional materials combining advanced properties and greater sustainability (Nisticò et al., 2020). The development of new building materials based on the principles of environmental sustainability is essential to meet the global requirements of a sustainable economy (Shanmugavel et al., 2020). According to Udomsap and Hallinger (2020) several studies have been carried out on the civil construction industry, and among the dominant lines of research is that of alternative materials for sustainable construction. In these studies, the use of biopolymers as an input in the generation of products in the civil construction industry appears as an alternative in the search for renewable resources and the replacement of petroleum as the main source of raw material for liquid fuels, chemical products and additives (Marsiet al., 2019).

At the same time, increasing scientific and technological cooperation has made it possible for researchers and inventors to share knowledge in different areas, experiences, resources and equipment, thereby increasing research efficiency and becoming an effective way to solve more complex problems, in addition to stimulating innovation (Zhang et al., 2021). According to Lubango (2020), international collaboration networks are a predictor variable for the ability of countries to produce and internationally disseminate inventions aimed at sustainable development and an alternative mechanism to support the development of relevant programs and policies in this regard, and as they accelerate transnational exchanges of human capital and adequately provide for the production and flow of innovations.

To examine the characteristics of innovation networks, the Social Network Analysis method (SNA) has been widely used. This method uses graph theory tools to assist in the analysis and description of the relationships of the various actors involved in a collaboration network (Liu et al., 2021). Cooperation between different organizations forms complex collaborative networks and SNA is used to interpret the roles and functions of these organizations in the collaborative innovation network, important to the understandingof how innovation is generated and disseminated (Yu et al., 2022). Therefore, the present study aims to identify and characterize the cooperation network formed between the various actors involved in the scientific production on innovations in the use of biopolymers in the civil construction industry.

II. METHODOLOGY

The study used data from scientific publications. An integrative systematic review was developed, focusing on a systematic literature review, considering all articles on a given topic and period, regardless of the type of methodology used (Botelho, Cunha & Macedo, 2011). Also according to the authors, this type of review is divided into six stages: formulation of the question, location of studies, critical evaluation of studies, data collection, data analysis and interpretation and knowledge synthesis.

The question that guides this research is: how are scientific cooperation networks on innovation based on the use of biopolymers by the civil construction industry characterized?

The documents that make up the scientific production were retrieved from the Scopus database, which offers a comprehensive overview of the production of works around the world in the areas of science, technology, medicine, social sciences, arts and humanities, and provides intelligent tools to monitor, analyze and view research, as well as elements for analyzing citations, references, among others (Elsevier, 2020). This database was chosen due to thesignificant number of documents widely recognized scientifically, in different areas.

The search was performed using the descriptors “biopolymer”, “building”, “construction” and “green polymer” and the connectors “OR” and “AND”, as titles, abstracts and keywords for workspublished between January 1st, 2010 and March 31st, 2022. As additional criteria for the inclusion of works, the only documents considered were primary studies, articles and reviews, in the areas of “Engineering” and “Environmental Science”, in English.

After an advanced search in the Scopus database, using the string TITLE-ABS-KEY ((biopolymer OR "green polymer") AND (construction OR building)) AND DOCTYPE (ar OR re) AND PUBYEAR > 1999 AND PUBYEAR < 2022 AND (LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "ENVI")), the titles and abstracts of the documents found were checked, to exclude those that were not related to the selected topic. Later, a detailed critical analysis of each document was done, to exclude the works that did not match the objective of the study.

In the analysis of knowledge collaboration, the Social Network Analysis method (SNA) was used. The method presents graphs that help synthesizeand verify relationships of the whole or parts and patterns (Booth, Sutton & Papaioannou, 2016) of the knowledge produced on biopolymers. Through the analysis of social networks, we seek to format the existing paths in the relationships

between people, organizations, and groups, among other elements, which, according to the terminology applied to this tool, are called the actors, represented by the nodes. The existing connections between actors are called links, represented by lines or edges, and the units of analysis of networks are the sets composed of groups of individuals and their interrelationships (Garton, Haythornthwaite & Wellman, 1997; Hanneman & Riddle, 2020).

Some specific metrics of SNA were used, including betweenness centrality, which investigates the nodes that take the shortest path to the other nodes (Brandes, 2001); degree centrality, which analyzes the number of connections per node (Williams et al., 2015); and modularity, which presents subgroups of nodes with greater proximity in a network (Paranyushkin, 2019).

The information relevant to the articles was exported to Microsoft Excel® spreadsheets, and the menu technique with each predefined category was then applied, to enable the use of codes of information retained from articles and patents (Wickham, Dunn & Sweeney, 2012). The Gephi® software was used as a tool for the structuring, visualization and analysis of social networks.

In addition, the National Indicators of Science, Technology and Innovation (2021) was consulted, to examine data on national expenditure on research and development (R&D), the number of articles published in scientific journals indexed by Scopus and the number of patent applications for inventions with the American Patent and Trademark Office (USPTO) and with the Patent Cooperation Treaty (PCT) by the countries leading the cooperation networks. The Global Innovation Index 2021 was also consulted to check the ranking of the countries with the highest performance in technological innovation, the budget allocations related to R,D&I, and to which income group these countries belong (WIPO, 2022).

III. RESULTS AND DISCUSSION

The search in Scopus databases, followed by a detailed critical analysis of each document, resulted in the compilation of 96 scientific publications on the use of biopolymers in the civil construction industry. Data regarding scientific production identified in the documents are presented in Table 1.

Table 1 - Scientificproduction

Database	**Numberofauthors**	**Numberofinstitutions/**	**Numberofcountries**	**Numberofscientificpublications**
Scopus	299	120	35	96

Source: The authors (2022).

The data in Table 1 show that the number of actors involved in the publication of scientific documents related to technological innovations on the use of biopolymers in the civil construction industry is quite substantial. The annual evolution of scientific publications between 2000 and 2022 is shown in Figure 1.

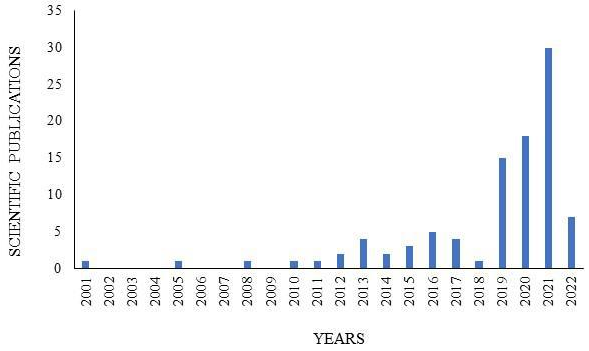

Fig.1 - Annual evolution of scientific production

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

The time series, shown in Figure 1, indicates that scientific production on the topic has grown over the years, even if irregularly.

Scientific production, although incipient, has experienced a significant increase in the number of publications from 2019 onwards, which shows that interest from the scientific community in the topic has been emphasized since then. This is probably due to the emergence of new demands that consider environmental issues. The drop in the number of publications in 2022 is due to the survey only accounting for the first three months of this year.

To carry out the SNA, the cooperation network related to scientific production was identified, in which the vertices, or nodes, represent the authors, organizations or countries involved, and the lines represent the relationships between them.

Table 2 indicates the degree centrality and the intermediation centrality of the most influential authors in the scientific cooperation network.

Table 2 - Degree centrality and intermediation centrality of the most influential authors in the network

Authors	Degree centrality	Intermediation centrality
Michael D. Lepech	22	88,33
Ilhan Chang	26	37,83
Sojeong Lee	20	18,33
Maria I. Allende	16	8,33
Jooyoung Im	18	7,83
Gye-Chun Cho	19	4,33
Minhyeong Lee	16	2,33
Isamar Rosa	10	1,33
Yeong-Man Kwon	14	0,33

Source: The authors (2022).

The results show that Ilhan Chang and Michael D. Lepech have the highest degree centrality values, 26 and 22, respectively, which indicates that more authors are directly connected to them than to other authors and that they occupy a prominent place in the network, influencing the other actors. Node degree centrality, in a graph structure, refers to the number of edges connected to a node (Yu et al., 2022) and reflects the direct connection between network members (Shiyu et al., 2020).

The two authors have the highest values of betweenness centrality, Michael D. Lepech with 88.33, and Ilhan Chang with 37.83. These values indicate that, in addition to being the most popular and influential authors, they also have a greater ability to control the flow of resources. Betweenness centrality refers to the number of times a member acts as a link between two other nodes (Shiyu et al., 2020). The measure assesses the relationships between an actor and two other actors in the network and measures the ability of actors to control resources (Liu et al., 2021).

Centrality metrics are tools widely used to characterize the nodes, or actors, of a network. In an SNA, the most important actors are those that relate to other actors more frequently, which makes them more visible, and considered more central in the network, and centrality measures try to describe the location of these actors in the network. (Zaoli, Mazzarisi & Lillo, 2021).

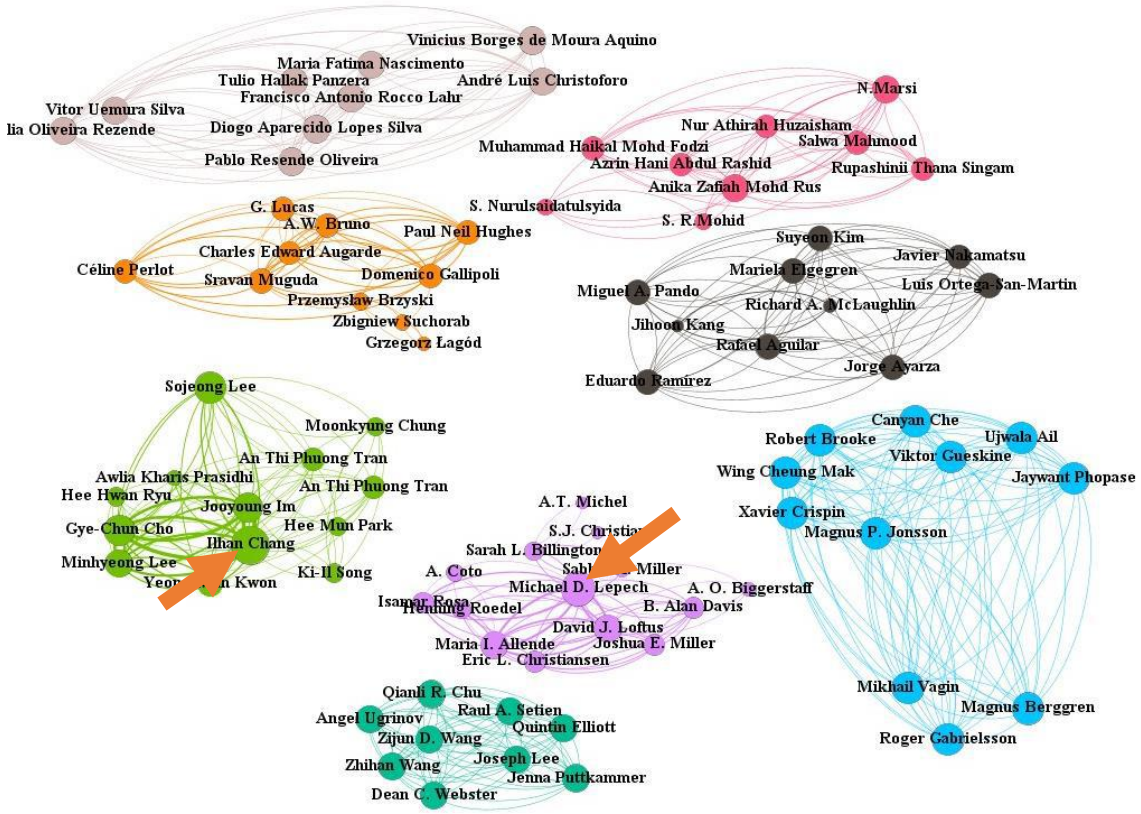

Fig.2 - Network formed by the authors of scientific production

Source: The authors (2022).

The authors considered the most important in the collaborative network, Ilhan Chang and Michael D. Lepech, have contributed significantly to the development of research on technological innovation based on the use of

biopolymers by the civil construction industry. Ilhan Chang has 9 publications on the topic and a total of 861 citations, while Michael D. Lepech has 6 publications and 39 citations. A detailed analysis of the documents obtained revealed that Ilhan Chang's studies were on the use of biopolymers in soil treatment and stabilization, and Michael D. Lepech's on the use of biopolymers as raw materials to replace conventional materials. Figure 2, based on modularity, shows the network formed by the authors of scientific production on the topic discussed.

Figure 2 was created from the calculation of the modularity of the network, through which the cooperation subgroups can be visualized, where the nodes, representing the authors, are more densely connected. Modularity measures the density of links within the network compared to links outside the network. This measure allows the identification of cooperation clusters, as it groups the nodes that are more densely connected to the rest of the network and defines communities according to the strength of their connections (Blondel et al., 2008).

Clusters are subgroups in a collaboration network and their identification reveals how many parts the network can be broken up into (Pineyrua, Ferreira & Biancolino, 2016; Scott, 2000). According to Figure 2, there are eight scientific cooperation clusters formed by the most influential authors on the subject. The larger nodes indicate authors that have a higher degree centrality, that is, those that are more important and influential within the network. The image also shows the authors who are in a more centralized position in their respective clusters, Ilhan Chang and Michael D. Lepech.

The analysis carried out with the data obtained through the Gephi® software and from scientific publications highlights that the worksby Ilhan Chang were in partnership with authors with different degree centralities and with values of betweenness centrality well below his own. Ilhan Chang leads the SURE3 Geotechnical Engineering Research Group at Ajou University. The letters in SURE3 stand for Sustainability, Urban utilization, Resilience, Environmental, Extreme and Emerging geotechnical engineering (SURE3, "s.d"). SURE3 also includes researchers Minhyeong Lee, from the Korea Advanced Institute of Science and Technology, and Sojeong Lee, from the University of New South Wales, who can be seen in the same cluster as Ilhan Chang.

Likewise, Michael D. Lepech developed studies in partnership with several authors with values of betweenness centrality well below his value and with different degree centralities. Michael D. Lepech is part of the Lepech Research Group at Stanford University, alongside A. O. Biggerstaff.

Apart from the clusters led by Ilhan Chang and Michael D. Lepech, most subgroups have their nodes with the same degree centrality or very close values, which correspond to less substantial cooperation clusters. According to Leng et al. (2021), a network may have several main nodes, but this makes the network less robust.

Regarding the organizations that are part of the scientific cooperation network, Table 3 shows the degree centrality and intermediation centrality of the most influential organizations.

Table 3 –Degree centrality and intermediation centrality of the most influential organizations in the network

Organizations	Degree centrality	Intermediation centrality
Korea Advanced Institute of Science and Technology (KAIST)	12	83
Korea Institute of Civil Engineering and Building Technology (KICT)	9	48
Hue University of Sciences	8	38
Universiti Teknologi Malaysia	14	28
University of New South Wales (UNSW)	6	21
Stanford University	8	6
Mansoura University	4	4
University of Sharjah	4	4

Source: The authors (2022).

Table 3 presents the best-connected organizations in the network, which are the Universiti Teknologi Malaysia, with a degree centrality of 14, and the Korea Advanced Institute of Science and Technology, with a degree centrality of 12. The values for betweenness centrality show that the Korea Advanced Institute of Science and Technology has a score of 83, well above the others, which indicates that it is the strongest organization in terms of controlling the flow of resources. Degree centrality is used to calculate how many and which actors are connected to the same node in the network. If a given actor has more connections than others, that indicates it has a higher centrality degree and it occupies a more important place in the network, influencing the other nodes (Liu et al., 2021; Pan et al., 2021). Betweenness centrality refers to the frequency with which a

node appears on routes connecting other pairs of nodes in the network and considers that communication is taking place along the shortest path between two nodes (Brandes, Borgatti & Freeman, 2016; Newman et al., 2020).

These metrics help analyze how organizations interact with the rest of the network and how important they are. They consider the different ways in which an organization connects with the rest of the network, and they allow the identification of those strategically located in the network, as the more centralized an actor is, the more important they are (Zaoli, Mazzarisi & Lillo, 2021).

Figure 3, based on modularity, presents the network formed by organizations involved in scientific production and adds to that analysis.

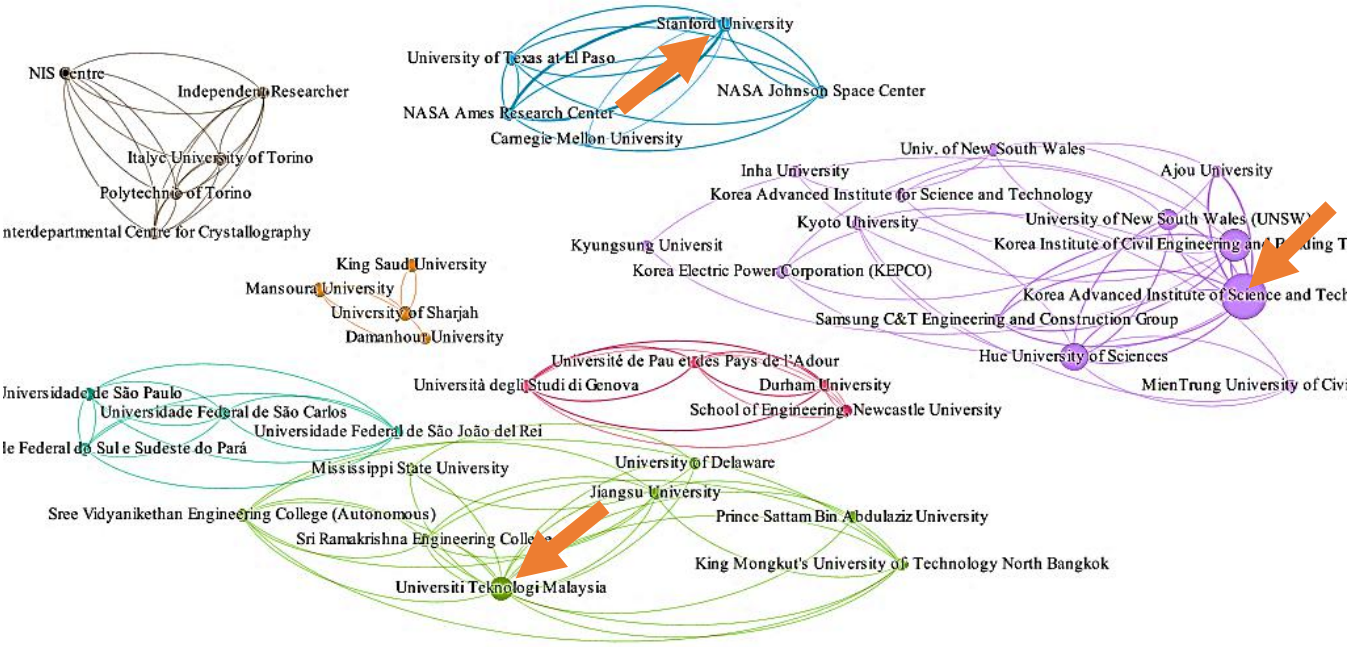

Fig.3 - Network formed by organizations involved in scientific production

Source: The authors (2022).

The most prominent collaborative clusters of organizations are found in the subgroup in purple, led by the Korea Advanced Institute of Science and Technology, located in South Korea. As seen earlier, the Institute, represented by the largest nodein Figure 3, has a higher degree centrality and intermediation centrality than the other actors, which means it is the organization with the most connections in its cluster, with relevant influence over the other members and with control over the resources. The Universiti Teknologi Malaysia and Stanford University also appear as leaders in their clusters. According to the present study, the second most influential author, Michael D. Lepech, carried out his research at Stanford University.

The division of the network into clusters is important as it helps to recognize which groups are more cohesive and the relationships between different groups. The division of a network into subgroups, modularity, is a characteristic of all social networks (Marcoux, Lusseau, 2013). Clusters can involve the participation and interaction of companies, as well as of various public and private institutions focused on instruction and training of human resources, research, development and engineering, policy, promotion and financing (Oliveira et al., 2012).

In addition to the aforementioned institutions, other prominent organizations in the network are the Korea Institute of Civil Engineering and Building Technology (KICT), Hue University of Sciences, and the University of New South Wales (UNSW), which all belong to the subgroup ledby the Korea Advanced Institute of Science and Technology (KAIST). The cluster is composed almost entirely of teaching and research institutions, with Samsung C&T Engineering and Construction Group and Korea Electric Power Corporation being the exceptions.

Scientific publications show that the most prominent author in the network, Ilhan Chang, developed his studies on the use of biopolymers in civil engineering as a representative of the Korea Institute of Civil Engineering and Building Technology (South Korea), the University of New South Wales (Australia) and Ajou University (South Korea), in partnership with authors who worked in South

Korean organizations, the Korea Advanced Institute of Science and Technology, the Korea Institute of Civil Engineering and Building Technology, Samsung C&T Engineering and Construction Group, Inha University, Ajou University, and Korea Electric Power Corporation, as well as with collaborators from the University of New South Wales (Australia) and Hue University of Sciences (Vietnam). These organizations all belong to the same cluster.

In the other subgroups, all actors are teaching institutions or research centers, with one of the clusters composed entirely of Brazilian universities: the University of São Paulo (USP), Federal University of São Carlos (UFSCar), Federal University of São João del-Rei (UFSJ) and Federal University of the South and Southeast of Pará (UNIFESSPA). The representatives of these institutions published the work "Circular vs. linear economy of building materials: A case study for particleboards made of recycled wood and biopolymer vs. conventional particleboards", in 2021, in the International Journal Construction and Building Materials.

Apart from the subgroups led by the Korea Advanced Institute of Science and Technology and the Universiti Teknologi Malaysia, there are several organizations with the same or very close values of degree centrality in the same cluster, which, according to Leng et al. (2021), means that these are less significant actors within the scientific cooperation network.

Figure 4, based on intermediation centrality, allows the visualization of the network of connections between the different countries, represented by circles, and their scientific production.

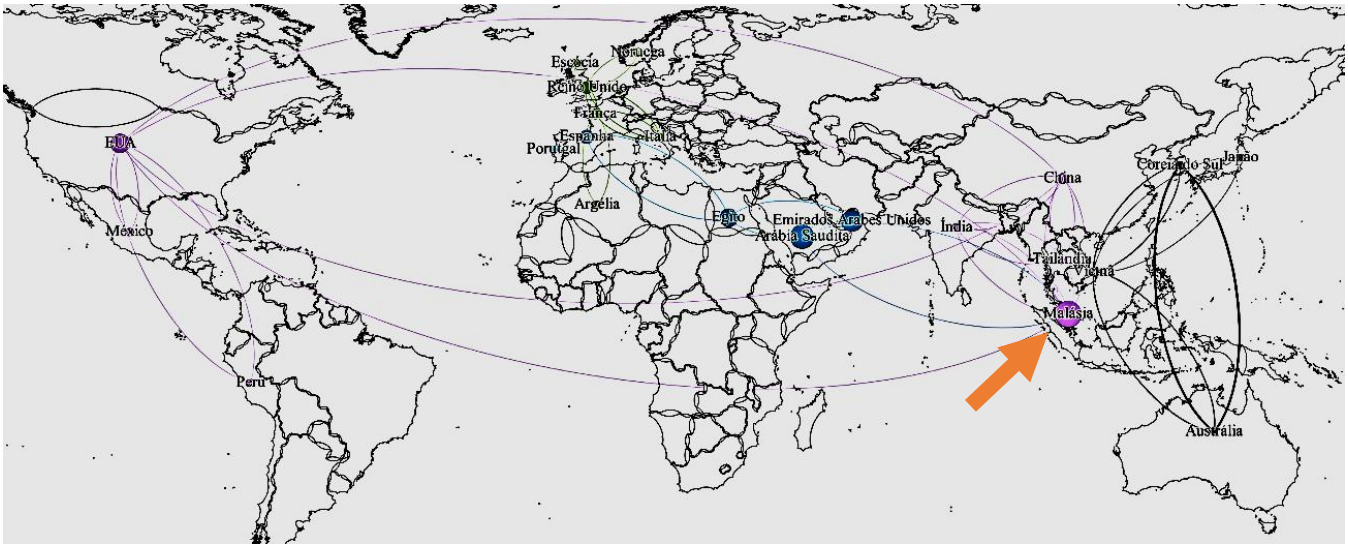

Fig.4 – Network formed by countries involved in the collaborative network

Source: The authors (2022).

Figure 4 shows the most active countries in the cooperation network of scientific production on technological innovation based on the use of biopolymers by the civil construction industry. In the map, we can see the collaborative clusters are composed of countries from different continents. The figure also shows thatregarding scientific publications, only 35 (thirty-five) countries participate in this collaborative network. Of these, the most prominent are Malaysia, Saudi Arabia, the United Arab Emirates (UAE), the United States of America (USA), Egypt, Spain, the United Kingdom, France, China and Vietnam. Table 4 below shows the degree centrality and intermediation centrality of the most relevant countries in the cooperation network.

The data in Table 4 show that Malaysia is the country with the most connections to other countries, with a degree centrality of 10 and intermediation centrality of 66, being the country that exerts greater control over resources and information in relation to the others, which is highlighted by the size of the node representing the country in Figure 4. The centrality of a node helps to verify the extent to which a network of technological innovation tends to focus on a particular actor (Leng et al., 2021), and betweenness centrality indicates the degree of control a node has over resources. A high value of betweenness centrality for a node means that it acts as a controller of the flow of resources (information, money, power, among others) to the other nodes connected to it (Ji et al., 2020). Scientific documents

show that Malaysia has produced studies in partnership with Saudi Arabia, China, the USA, India and Thailand.

Table 4 - Degree centrality and intermediation centrality of countries

Countries	Degree centrality	Intermediation centrality
Malaysia	10	66
Saudi Arabia	4	56
UAE	4	48
USA	8	38
Egypt	4	36
Spain	4	20
United Kingdom	8	14
France	6	8
China	8	6
Vietnam	6	4

Source: The authors (2022).

According to the Global Innovation Index 2021, of the countries mentioned in Table 4, Saudi Arabia, the UAE, the USA, Spain, the United Kingdom and France are in the high-income group. Malaysia and China belong to the upper-middle-income group, and Egypt and Vietnam are part of the lower-middle-income group. The United Kingdom, the USA, China, and the UAE are among the top three innovation economies by region, and Malaysia and Vietnam are among the top three innovation economies by income group. In 2021, France occupied the 11th position in the global ranking (Wipo, 2022).

In 2014, the government of the United Arab Emirate (UAE) adopted the National Innovation Strategy, intending to make the country one of the most innovative in the world, in addition to achieving the Sustainable Development Goals, defined in the United Nations Summit of 2015 and included in the 2030 Agenda. The strategy focuses mainly on renewable energy, transportation, education, health, solving water scarcity, and new technologies (Krzymowski, 2020). The UAE's government, which has a well-defined vision for its development and is committed to achieving exceptional results in terms of economy, society and the environment, guides its bodies to work per the highest standards, based on models of performance and innovation (UAE, 2017).

The data published in the National Indicators of Science, Technology and Innovation (2021) show that, concerning national expenditures on research and development (R&D) betweenthe years 2000 and 2019, the USA ranked first for that entire period, with the largest percentage of funding coming from companies rather than the government. Likewise, the country also stands out in the number of articles published in scientific journals indexed by Scopus and in the number of applications for patents for inventions with the American Patent and Trademark Office (USPTO) and the Patent Cooperation Treaty (PCT) from 2000 to 2020.

International comparisons described in the National Indicators of Science, Technology and Innovation (2021), show that Chinese national expenditures on research and development (R&D) increased significantly between 2000 and 2019, with figures second only to the USA. The report also shows that in China, Spain, the United Kingdom and France, the largest percentage of the expenditures are financed by companies and not by the government.

According to scientific publications, only 22.9% of the 96 articles were developed in partnership between the countries. The most robust collaborative cluster, led by South Korea, is mainly composed of South Korean members, having only two organizations outside of the country, the University of New South Wales (Australia) and Hue University of Sciences (Vietnam).

IV. CONCLUSIONS

The Social Network Analysis showed that in the scientific cooperation network there are few clusters of authors and organizations with research on the topic, which indicates that few studies were developed in partnership with other countries, about 22.9%.

All organizations that make up the subgroups of the cooperation network are teaching and research institutions, except for Samsung C&T Engineering and Construction Group and Korea Electric Power Corporation, actors in the cluster led by the Korea Advanced Institute of Science and Technology. Although the collaborative network contains countries from different continents, only 35 countries participate in the scientific production network on the technological innovation considered in this study.

South Korea stands out in scientific production. However, most collaborations involving South Korean organizations happen within the country, with the University of New South Wales, in Australia, and Hue University of Sciences, in Vietnam, being the only foreign organizations in their cluster.

There was a tendency for scientific research on the innovation explored in this study to expand over time. Therefore, it is recommended that similar studies be carried

out in the future, to verify the behavior of these collaborative networks in the coming years.

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