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Scientific Collaboration Networks Among Researchers and Social Network Analysis: A Systematic Literature Review

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Abstract
Scientific collaboration networks as a research area have been the focus of the scientific community for years, across various disciplines and subjects, including health-medicine, economics, engineering, social sciences, environment, technology, and many more. In this systematic literature review, scientific collaboration networks have been examined using social networking analysis, focusing on data extracted from Scopus, Web of Science, ScienceDirect, and SpringerLink, resulting in 348 articles, published from 1984 onwards. This review attempts to answer three research questions: 1) how research on scientific collaboration networks has evolved throughout the years, 2) what the focus of the literature on scientific collaboration networks is and, 3) how Social Network Analysis has been used in the context of scientific collaboration network studies. The study revealed a surge in publications, mainly from 2016 onwards, with most of the articles focusing on health-medicine, technology, and environmental issues. By examining authors, institutions, universities, countries, and citations, this review seeks to reveal new trends, collaboration, structural patterns, influential actors, and dynamics of the field. Social networking analysis is combined with many other methodologies and techniques, like network construction, descriptive analysis, statistics, longitudinal analysis, Machine Learning and AI, and community detection, revealing research gaps, like the need for interdisciplinarity and international scientific collaboration, gender-based and peripheral actors' studies. Finally, this review underlines the potential for studying scientific collaboration networks in regions with less representation.

Keywords: Scientific collaboration networks; social network analysis; systematic literature review
JEL Classification: D85; I23

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1. Introduction

Social Networking Analysis (SNA) has been used in a wide range of scientific fields, such as social and economic sciences, but also in a multitude of others like medicine, engineering etc. There is no generally accepted definition of SNA as a scientific field. It has been characterized

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at times as a theory, a strategy, an approach, but also as a set of techniques (Buch-Hansen, 2014). Marin & Wellman (2011), use the term "paradigm" apart from theory and methodology. The main goal of Social Networking Analysis is the analysis of the social relationships of individuals, the structure of these relationships and the way these relationships influence social behavior and attitudes (Prell, 2011). As Freeman (2004) emphasizes, social structure is formed by the patterns of relationships that individuals develop with each other when they interact. Therefore, the concept of interaction between individuals is important (Wasserman & Faust, 1994; Marin & Wellman, 2011). This interaction, the quality of the relationship that develops, the time an individual interacts with another one, the duration of this relationship, are particularly important and bring about changes both in the individuals and in the entire network that is formed (Freeman, 2004).

In the context of Social Networking Analysis, the study of collaborative networks also includes networks formed by the collaboration between various entities, such as organizations, and by the scientific collaboration of researchers in the context of publishing a scientific article. In recent years, there has been a heightened interest in research on collaborative networks and the characteristics they develop at both micro and macro levels (Camarinha-Matos & Afsarmanesh, 2004). With the abundance of data and computational techniques, this method is receiving significant recognition (Di Bella et al., 2021).

Collaboration networks examine the structure, behavior, and dynamics of individuals interacting to achieve a goal. They are composed of different entities that are autonomous, geographically distributed, and heterogeneous in terms of the environments in which they operate, the culture and society in which they live, and the goals they have; when these entities collaborate, they aim to achieve common goals. Their actions are examined with computational networks (Camarinha-Matos & Afsarmanesh, 2004). They considered it important that the concept of collaborative networks should constitute a separate scientific discipline with its principles, practices, and a qualified scientific community. The development of Information and Communication Technologies, the increased social and business needs, and the progress made at the level of international planning led to the ever-increasing importance that collaborative networks take on in various sectors of society (Camarinha-Matos & Afsarmanesh, 2004).

Collaborative networks, for example, are extremely important in gaining a competitive advantage in the constantly changing business environment, so much so that researchers suggest that the sustainability of businesses depends on whether they are integrated into collective collaborative networks (Hwang et al., 2008). The concept of collaborative networks is also important in other contexts, such as in the public sector (Mischen, 2015), in educational institutions (Noran, 2013), and even in the tourism sector (Larson & Gyimóthy, 2013). What is important is the creation of groups, e.g., collaboration groups between businesses (customers and partners) (Ozcan & Islam, 2014) and collaboration networks between educational institutions (even between researchers) (Di Bella et al., 2021). This collaboration therefore results in the creation of networks that aim to achieve collective goals through joint effort. The benefit of this collaboration takes the form of programs, products, goods, and scientific production, depending on the area of interest (Lai et al., 2012).

Such collaborative networks are also those created by scientific collaboration between researchers in the context of the joint effort to write a scientific article. Universities and their academic staff are considered a significant source of knowledge production, contributing significantly to academic progress (Grigore et al., 2009). In recent years, there has been increased interest in research on scientific collaboration between researchers which follows from an ever-increasing trend of collaboration among researchers (Di Bella et al., 2021).

Newman (2001), for example, points out that the scientific collaboration networks that are created are the result of the joint effort to write articles that are linked to each other through two or more authors-researchers. Each researcher constitutes a node in the network, and these nodes are connected by a set of lines, which indicate the collaboration patterns between them. Two researchers are considered connected if they have written at least one article together which shows, minimally, that they know each other to some extent. This, however, does not mean that personal acquaintances always entail more joint publications; researchers might have personal relationships with each other and yet no collaborative publication. Such collaboration networks are found in various scientific fields, showing an increased interest in the subject (Henriksen, 2016; Kuld & O' Hagan, 2018). This collaboration helps to overcome the obstacles posed by the complexity and specialization of scientific research through the joint effort of scientists within and across scientific disciplines. This interdisciplinarity allows researchers to explore new ideas, acquire new skills, and broaden their knowledge. Collaboration also increases the volume of writing and the quality of scientific articles (De Stefano et al., 2010) and can even reduce the potential cost of a publication since the authors share the cost. Joint scientific writing between various scientific disciplines has been of considerable concern and in this context, the networks of cooperation between the scientific staff of specific educational institutions could also be studied.

The present paper aims to dive into the scientific collaborative network research by conducting a systematic literature review (SLR). In contrast with the traditional literature review, SLR focuses on framing questions, searching relevant studies, assessing their quality, summarizing the information, and discussing the findings (Khan et al., 2003). Kitchenham & Charters (2007) mention that "Systematic literature review (also referred to as a systematic review) is a form of secondary study that uses a well-defined methodology to identify, analyze and interpret all available evidence related to a specific research question in a way that is unbiased and (to a degree) repeatable". Also, Moher et al. (2009) mention that "A systematic review is an overview of a clearly worded question that uses systematic and explicit methods to identify, select and critically evaluate relevant research and to collect and analyze data from the studies included in the review." This study attempts to collect, analyze, and synthesize all the current studies on scientific collaboration networks that use social network analysis from 1984 onwards.

Specifically, in this paper we attempt to answer the following research questions:

RQ1: How research on scientific collaboration networks has been studied through the years?

RQ2: What is the focus of the literature on scientific collaboration networks?

RQ3: How Social Network Analysis has been used in the context of scientific collaboration network studies?

The paper is organized as follows. In the second section, the systematic literature review method is laid out, including the review protocol, the exclusion and inclusion criteria, the databases used to collect data from, the relevant studies, and the searched items-keywords. In the third section, the paper presents an analysis of the selected studies, followed by a discussion of the findings. In the fourth section, conclusions, implications, possible limitations, and suggestions for further research are presented.

2. Methodology of systematic literature review (SLR)

To answer the above questions, this paper uses a systematic literature review approach (SLR). Traditional literature reviews have been criticized as a more personal, subjective and biased approach-methodology adopted by researchers through the years (Hart, 1998; Henttonen, 2010). Therefore, as Tranfield et al. (2003) suggested, a more systematic approach, by following the principles of the systematic review, is a more transparent process. Fiegen (2010) described SLR as "a model for summarizing and critiquing literature to improve future practice and possibly encourage higher levels of research methods. A systematic literature review of 30 years should reveal evidence toward a maturing research methodology". Also, Kitchenham and Charters (2007) mention that "Systematic literature review is a form of secondary study that uses a well-defined methodology to identify, analyze and interpret all available evidence related to a specific research question in a way that is unbiased and (to a degree) repeatable". Khan et al. (2003) pointed out that SLR "is based on a clearly formulated question, identifies relevant studies, appraises their quality and summarizes the evidence by use of explicit methodology. It is the explicit and systematic approach that distinguishes systematic reviews from traditional reviews and commentaries".

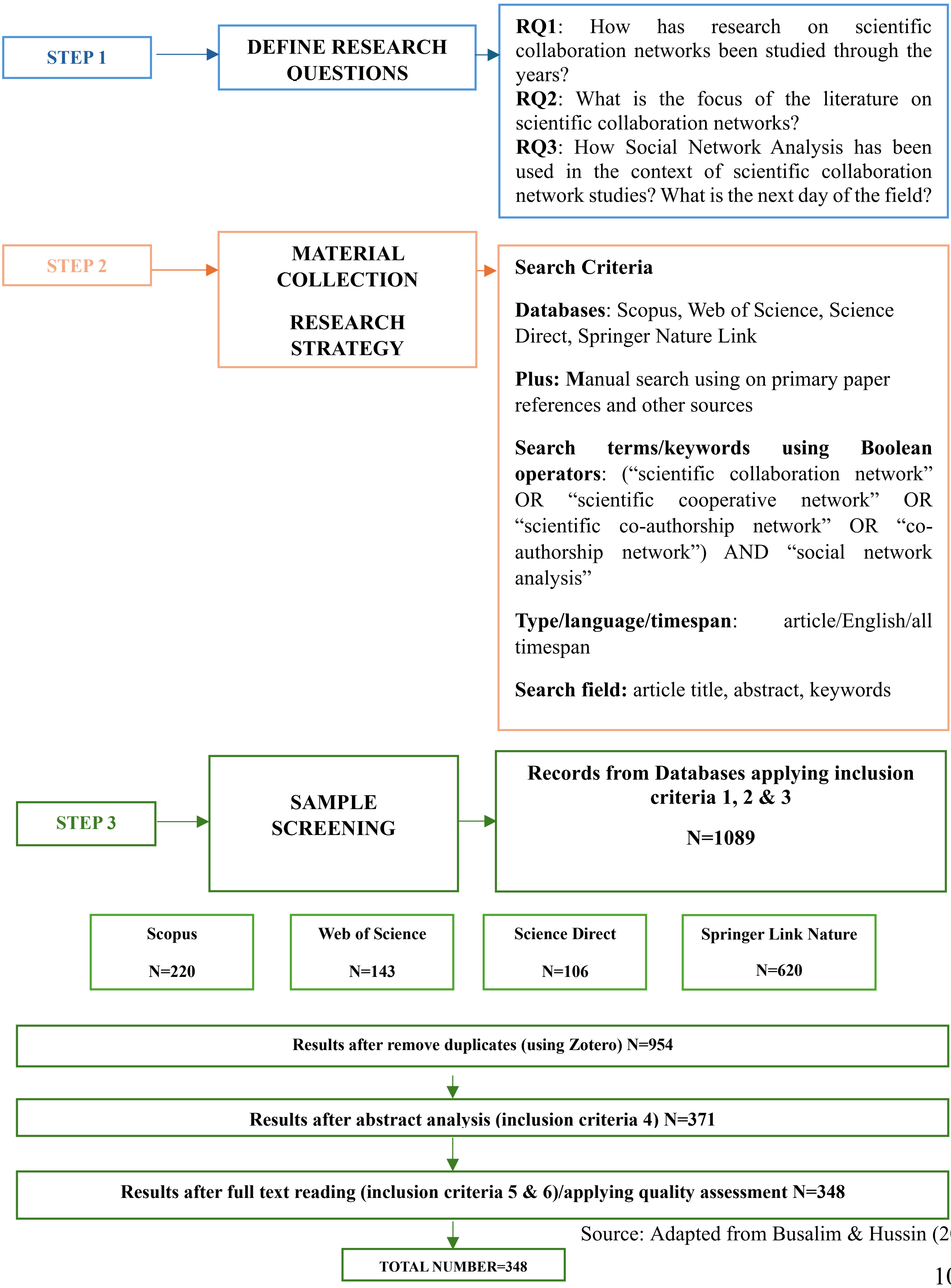
Three steps are considered important in conducting an SLR, "planning the review", "conducting the review", and "reporting the review". More specifically, we need to define:

- the research questions
- the review protocol
- the literature search strategy-research design and study selection process
- the exclusion and inclusion criteria
- and finally, analyze the findings (including answering the research questions) (Gomezelj, 2016; Ahmed et al., 2021).

2.1 Systematic literature review protocol

A very important step in every systematic literature review is the review protocol. The protocol is the exact methodology each researcher adopts to do the review. It contains research questions, the search strategy, the selection and the evaluation process, the selected data and the synthesis of the data (Busalim & Hussin, 2016; Filenta & Kydros, 2022). Figure 1 shows the exact review protocol followed in this paper (adapted from Busalim & Hussin, 2016). The first step of our review protocol includes the research questions. First, we examine the question of the extent to which scientific collaboration networks have been studied through the years in the large pool of articles. In this direction, we present the selected articles per year of publication, per scientific journal, per subject area, and finally, we examine the citations for each article. With this, we aim to find the distribution of publications through the years, discovering the most productive periods on the subject. In short, this distribution shows the evolution of scientific collaboration networks through the years. To assess the quality of the selected articles, we use two complementary criteria. First, we classify articles according to the scientific journal in which they were published, using the journal's impact factor as an indicator of the outlet's overall prestige and rigor. Second, we classify articles individually according to their citation count, which reflects the impact and relevance of each specific article within the research community. While a high-impact journal does not guarantee that every article it publishes will be highly cited, and a highly cited article may appear in a lower-impact journal, together these two criteria provide a more balanced assessment of both the quality of the publication venue and the influence of the individual contribution. In the next research question, we categorize the articles depending on their topic, the size they use, the research period they choose to examine, and the country or countries from which their sample was drawn. In the last research question, we analyze the articles depending on their methodology. Since we chose to study articles that use social networking analysis, we want to examine the way they use it or if they combine it with other methods.

Figure 1. Review Protocol



Source: Adapted from Busalim & Hussin (2016)

2.2 Research strategy

The second step refers to the research strategy that includes two essential stages. The first stage has to do with the automatic search to find the primary studies from the selected databases. We select several databases to cover a broader range of publications (Busalim & Hussin, 2016; Avramchuk & Hlyvanska, 2018). We selected Scopus, Web of Science, Science Direct and Springer Nature Link. These databases cover a large number of publications in a broad range of scientific fields and many researchers who conduct SLR use them (Busalim & Hussin, 2016; Krupoderova & Portnov, 2020; Ahmed et al., 2021; Nerantzidis et al., 2022). Web of Science for example is considered the "world's most extensive database of scientific citation, analytical information and more, it is a significant scientific tool across countries and knowledge domains, used by global scientists in different ways to answer scientific questions" (Da Costa Leonidio et al., 2023).

In the research process, using the Boolean operators OR and AND, we search using the following pattern ("scientific collaboration network" OR "scientific cooperative network" OR "scientific co-authorship network" OR "co-authorship network") AND "social network analysis". We chose to search these keyworks within the title, the abstract or the keywords of the article (Webster & Watson, 2002; Krupoderova & Portnov, 2020). According to the criteria we discuss in section 2.3, in step three, we proceed with data screening. We chose only articles as the document type, English as the language, without selecting a year range, or subject area (inclusion criteria 1,2, and 3). The second step also involves the manual search of important articles. This step is a back/forward process to find relevant articles by searching in Google Scholar, or in the references of the most cited articles. Using Zotero, a tool to handle references, we ended up with a total number of n=1089. With this tool, we exclude duplicate articles, resulting in 954 articles. The whole filtering process depends on the following inclusion and exclusion criteria (section 2.3). Besides that, we examine the remaining articles by their abstract to exclude many more. The remaining articles were examined by a full-text reading and ending in those that use social networking analysis. The final number of articles is n=348 and these articles are fully examined to answer the research questions.

Table 1. Keywords in the searching process

Keywords used in the searching process using Boolean operators OR/AND
("scientific collaboration network" OR "scientific cooperative network" OR "scientific co-authorship network" OR "co-authorship network") AND "social network analysis"

Source: own research

2.3 Inclusion and Exclusion Criteria

To select only those articles that are relevant to our study, we identified certain inclusion/exclusion criteria. These criteria helped us during steps two and three of the review protocol. We chose to study only articles that are written in English through an open timespan period. After deleting the duplicates, we chose those relevant to our study by reading the abstracts of the remaining articles. And then we fully read the text to come to the necessary conclusions.

Table 2. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Articles as document type	Conference paper, Review, Book chapter, proceeding articles, Conference review, notes.
English as the language of the articles	Other languages besides English
No timespan limitations	Irrelevant topics
Related to the topic of interest based on the abstract	Uncompleted articles
Related to the topic of interest based on full-text reading	Duplicated studies
Use social networking analysis or combined methods	Using other methodologies
Pass the quality assessment process	Not completing the quality assessment process

Source: own research

2.4 Study selection process

In this section we identify those articles that are the most relevant to our study and our research questions. After searching in the above-mentioned databases (see figure 1) using the inclusion criteria 1, 2 and 3 (see table 2), the search identified 1089 articles. Most of them were found on Springer Link Nature platform (total number of 620 articles), followed by Scopus (220 articles), Web of Science with 143 articles, and finally Science Direct with 106 articles. After removing duplicated articles using Zotero, a free and open-source software for creating bibliographic references and related material, 954 articles remained. In the process of abstract screening, we try to evaluate each article including those that are relevant to our study depending on the abstract. A total number of 371 articles ended up being relevant. As Busalim & Hussin (2016) and Kitchenham and Charters (2007) mentioned in this process we keep those articles that seem to be clearly relevant to our study, eliminating the rest of them. The following step is the full-text screening process, where each article is examined more thoroughly applying inclusion criteria 5 and 6, and quality assessment. During this process we search for specific information like the author's names, the publication date, the publication journal, the publisher, the main subject of each research article, the sample size, the research period, the methodology used, the results of the research etc. This step helps us answer our research questions. The remaining articles were 348.

2.5 Quality Assessment

In addition to seeking articles that contain the above information (see 2.4 section), we also apply quality assessment (Kitchenham and Charters, 2007; Busalim & Hussin, 2016). During full-text screening, each time we read an article we try to answer certain quality assessment questions.

Table 3. Quality Assessment Questions

Quality Assessment Questions
Is the main subject of the article related to our research?
Does it refer to the scientific field of scientific collaboration networks?
Is the methodology described in the paper?
Do they use social networking analysis?
Are the sample size and the data collection process described in the paper?
Is the analysis of the data described in the paper?
Are the results clearly presented?

Source: own research

We concluded that 348 articles pass the quality assessment procedure and can therefore be included in our research. The selected databases also supplement the reliability of the selected articles. Scopus, Science Direct, Web of Science, and Springer Link Nature are considered reliable databases for academic research (Zhu & Liu, 2020).

3. Results

3.1. Research on scientific collaboration networks throughout the years

In this section, we aim to answer how scientific collaboration networks have been studied throughout the years, presenting all the information needed from the 348 articles. In Table 4 we list the kind of information we extracted while reading each paper which will help us answer our research questions.

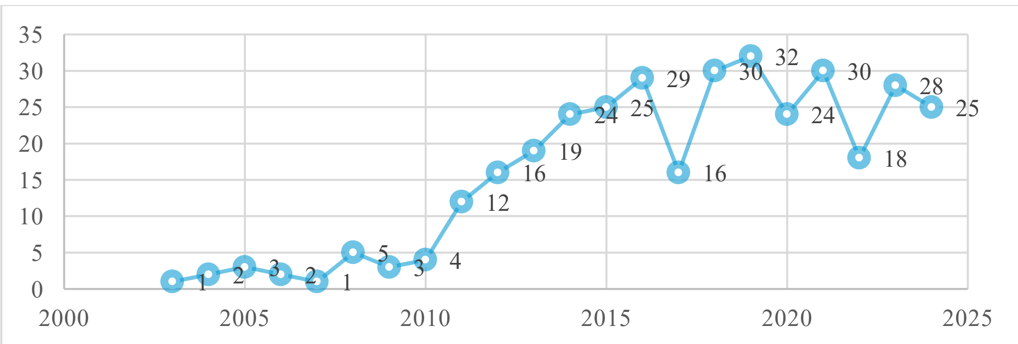
Table 4. Categories of information extracted

Publication date	Research period-time span
Authors names	Countries studied
Journal	Sample size
Publisher	Methodology
Citations	The way they use Social Networking Analysis
The subject of the paper	The results of each study

Source: own research

With research question RQ1, we are looking to provide answers on how the field of scientific collaboration networks has evolved throughout the years. More specifically, we study those papers that use social networking Analysis (SNA) trying to map out how researchers study this scientific field using this methodology (or combining SNA with other methodologies). We first examine the temporal aspect of these publications which is available in Figure 2. It seems that publications have increased over the years, from only 1 publication in 2003 to a maximum of 32 publications in 2019. We also see some fluctuation in the frequency of publications in recent years, as scientific fields are not stable, i.e., are amenable to restructuring by the introduction of new and promising ideas. As is shown in the figure there is an ever-increasing interest in the field of scientific collaboration networks, with most articles being published from 2016 onwards.

Figure 2. Publications per year



Source: own research

All 348 articles included in this systematic literature review were published in scientific journals. Complemented with the basic information for the selected articles, Table 5 lists the top 14 journals in which most articles of our review have been published. For readability purposes, we have included in the table the journals that contain three or more relevant publications and excluded those where only one or two articles were recorded. The more publications a journal has on a specific topic, the more related it is to our topic. As we can see, Scientometrics has a total of 104 papers published, followed by the Journal of Informetrics with 10 articles, Health Research Policy and Systems and PLOS ONE with 6 articles, International Journal of Information Science and Management with 5 articles, Quality & Quantity, Sustainability (Switzerland) and Journal of Cleaner Production with 4 articles, and finally Automation in Construction, Library Philosophy and Practice, Aslib Journal of Information Management, Malaysian Journal of Library and Information Science, The Journal of Technology Transfer, Social Network Analysis and Mining, and PLoS Neglected Tropical Diseases with 3 articles. The remaining journals recorded during the systematic review had only one article. The table also lists the publisher of each journal, the ranking of each journal depending on Web of Science impact factors and Scimago Ranking. The higher an impact factor or a H-INDEX score is the more highly ranked a journal is considered. Because each list indexes journals based on its own criteria, some journals only appear in one of the lists or, rarely, in neither. This is why we chose to include rankings from two different platforms.

Table 5. Journal ranking (impact factor, H-index)

Journals	**Publisher**	**Web of Science Impact Factors**	**Scimago Ranking H-INDEX**	**Number of papers**
Scientometrics	Springer-Verlag	3.5	144	104
Journal of Informetrics	Elsevier	3.4	90	10
Health Research Policy and Systems	Springer (Biomed Central Ltd.)	3.6	69	6
PLOS ONE	Public Library of Science	2.9	435	6
International Journal of Information Science and Management	Regional Information Center for Science and Technology	not in list	14	5
Quality & Quantity	Springer Neitherlands	not in list	78	4
Sustainability (Switzerland)	MDPI	3.3	169	4
Journal of Cleaner Production	Elsevier	9.7	309	4
Automation in Construction	Elsevier	9.6	176	3
Library Philosophy and Practice	University of Science and Technology Beijing	not in list	27	3
Aslib Journal of Information Management	Emerald (MCB UP)	2.4	50	3
Malaysian Journal of Library and Information Science	Faculty of Computer Science and Information Technology	not in list	29	3
Social Network Analysis and Mining	Springer-Verlag	2.3	48	3
PLoS Neglected Tropical Diseases	Public Library of Science	3.4	163	3

Source: own research

In the process of collecting and processing the data, we noted the most cited articles with at least 100 citations and listed them in Table 6.

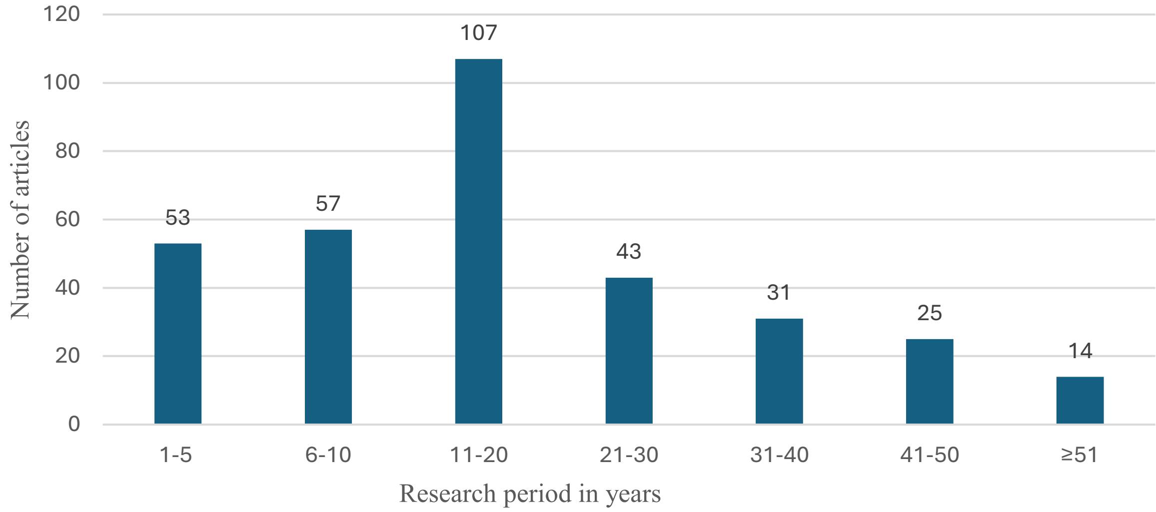
Table 6. List of articles with ≥100 citations

Authors	Title	Journal	Publisher	Impact Factor	H	Citat ions	Subject area
Liu et al., 2005	Co-authorship networks in the digital library research community	Information Processing and Management	Elsevier Ltd	Not in list	123	652	Computer Science/Decision Sciences/Engineering/Social Sciences
Hosseini et al., 2018	Critical evaluation of off-site construction research: A Scientometric analysis	Automation in Construction	Elsevier	9.6	176	477	Construction Building Technology/ Engineering
Abbasi et al., 2011	Identifying the effects of co-authorship networks on the performance of scholars: A correlation and regression analysis of performance measures and social network analysis measures	Journal of Informetrics	Elsevier	3.4	90	383	Computer Science/ Social Sciences
Li et al., 2013	Co-authorship networks and research impact: A social capital perspective	Research Policy	Elsevier	7.6	289	356	Business Economics/ Engineering
Bozeman et al., 2013	Research collaboration in universities and academic entrepreneurship: the-state-of-the-art	The Journal of Technology Transfer	Kluwer Academic Publishers	Not in list	Not in list	329	Business, Management and Accounting/ Decision Sciences
Khan et al., 2019	Methodological research on partial least squares structural equation modeling (PLS-SEM): An analysis based on social network approaches	Internet Research	Emerald (MCB UP)	5.9	109	263	Economics, Econometrics and Finance/ Social Sciences
Darko et al., 2019	A scientometric analysis and visualization of global green building research	Building and Environment	Elsevier	7.1	205	238	Construction Building Technology/ Engineering
Zhong et al., 2019	A scientometric analysis and critical review of construction related ontology research	Automation in Construction	Elsevier	9.6	176	204	Construction Building Technology/ Engineering
Hou et al., 2008	The structure of scientific collaboration networks in Scientometrics	Scientometrics	Springer-Verlag	3.5	144	171	Computer Science/ Social Sciences
Kumar, 2014	Co-authorship networks: A review of the literature	Aslib Journal of Information Management	Emerald (MCB UP)	2.4	50	161	Computer Science/ Social Sciences

Koseoglu 2016	Growth and structure of authorship and co-authorship network in the strategic management realm: Evidence from the Strategic Management Journal	BRQ Business Research Quarterly	Elsevier B.V.	Not in list	41	161	Business, Management and Accounting/ Economics, Econometrics and Finance
Gui et al., 2019	Globalization of science and international scientific collaboration: A network perspective	Geoforum	Elsevier	3.4	141	160	Social Sciences
Fonseca et al., 2016	Co-authorship network analysis in health research: method and potential use	Health Research Policy and Systems	Springer (Biomed Central Ltd.)	3.6	69	153	Health Care Sciences Services
Abbasi et al., 2012	Egocentric analysis of co-authorship network structure, position and performance	Information Processing and Management	Elsevier Ltd	Not in list	123	151	Computer Science/ Decision Sciences/ Engineering/ Social Sciences
Morel et al., 2009	Co-authorship network analysis: a powerful tool for strategic planning of research, development and capacity building programs on neglected diseases	PLoS Neglected Tropical Diseases	Public Library of Science	3.4	163	135	Medicine
Uddin et al., 2013	Network Effects on Scientific Collaborations	PLoS ONE	Public Library of Science	2.9	435	118	Agricultural and Biological Sciences/ Biochemistry, Genetics and Molecular Biology/ Multidisciplinary
Uddin et al., 2012	Trend and efficiency analysis of co-authorship network	Scientometrics	Springer-Verlag	3.5	144	113	Computer Science/ Social Sciences/ Information Science Library Science
Sarigöl et al., 2014	Predicting scientific success based on coauthorship networks	EPJ Data Science	Springer Science & Business Media	3	43	113	Computer Science/ Mathematics
Peng et al., 2022	Bibliometric and visualized analysis of ocular drug delivery from 2001 to 2020	Journal of Controlled Release	Elsevier	10.5	313	105	Chemistry/ Pharmacology Pharmacy
Perc, 2010	Growth and structure of Slovenia's scientific collaboration network	Journal of Informetrics	Elsevier	3.4	90	103	Computer Science/ Social Sciences
Borrett et al., 2014	The rise of Network Ecology: Maps of the topic diversity and scientific collaboration	Ecological Modelling	Elsevier	2.6	181	103	Environmental Science

Another important element in understanding the state of research on scientific collaboration networks is the period each article examines. From 348 articles, 330 explicitly mention the timespan they examine, and only 18 do not make any concrete reference to the timespan they investigate. Figure 3 shows how many articles examine a specific period in years: the x-axis presents the research period in years that each article examines (1-5, 6-10, 11-20, 21-30, 31-40, 41-50, and ≥51); the y-axis presents the number of articles that share the same timespan covered. For example, 25 publications studied a period of 41-50 years. Most of the articles discuss the early 21st century period, from 2000 to 2020, which is also evident in the figure (107 articles cover a timespan of 11-20 years of research). This indicates that there has been a significant focus on recent research over the last 20 years (the most cited research periods are 2000-2010 and 2010-2020, which span the first 20 years of the twenty-first century; 2006-2010, 2001-2010, 2010-2020, and 2005-2015 also have regular appearances).

Figure 3. Frequency distribution of the time span (in years) examined in each study

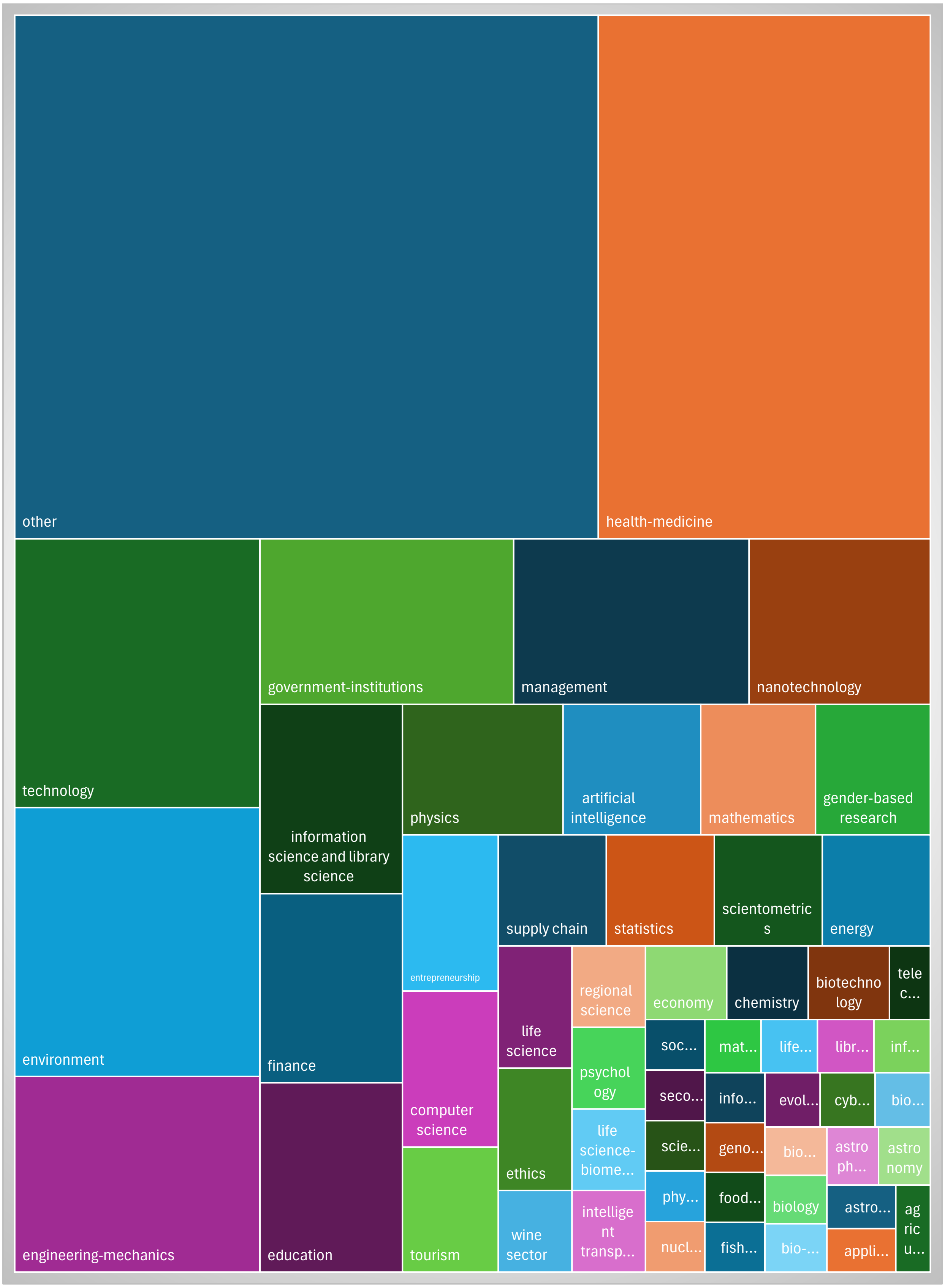


Source: own research

3.2.The focus of the literature on scientific collaboration networks

In this section, we examine the basic subjects found within the literature, aiming to identify trends in the field of scientific collaboration networks. To do so, we read all 348 articles trying to find the main subject or scientific area each one examines. The theme or subject is the main topic of the article and is the main issue each article tries to investigate (Liang & Turban, 2011; Busalim & Hussin, 2016). Our categorization yielded 57 subjects or themes (e.g., environment) which are available in Table 7 along with the total count they have been examined and their percentile appearance across the 348 articles. Most articles have one clear subject but many of them explore more than one subject or theme. That is why from a total of 348 articles we ended up with a total of 384 themes examined.

Figure 4. Main subjects of articles



Source: own research

In Figure 4, we have created a treemap of the main subjects of literature. The 20 most frequent subjects are the following: other, health-medicine, technology, environment, engineering-mechanics, government-institutions, management, nanotechnology, information science and library science, finance, education, physics, artificial intelligence, mathematics, gender-based research, entrepreneurship, computer science, tourism, supply chain, and statistics. The category “other” takes up the majority of the treemap; these articles are labeled “other” because they do not conduct research about a specific scientific area but are more technical articles examining more methodological issues or the field of scientific collaboration networks from a more general point of view. For example, “The Evolution of Social Work from Disconnected Groups to a Scientific Community: A Social Network Analysis” by Eckl et al., 2019, examines structural features of the networks, and social structure of the social work discipline, emphasizing the interplay between collaboration dynamics, inequality, and knowledge production. Another example is “The evolution of your success lies at the centre of your co-authorship network” by Servia-Rodríguez et al., 2015, examining the relationship between an author's success in academic research, measured through publications and citations, not focusing on a specific theme-research area. The rest of the articles explicitly examine the field of scientific collaboration networks concentrating on a more specific research theme, like health-medicine, technology, environment, etc.

Table 7. Subjects of articles

Category	Count (articles on this subject)	Percentage (count*100/total)	Percentage %
other	102	26.5625	26.56%
health-medicine	58	15.10416667	15.10%
technology	22	5.729166667	5.73%
environment	22	5.729166667	5.73%
engeeniring-mechanics	16	4.166666667	4.17%
govenrnment-institutions	14	3.645833333	3.64%
management	13	3.385416667	3.39%
nanotechnology	10	2.604166667	2.60%
information science and library science	9	2.34375	2.34%
finance	9	2.34375	2.34%
education	9	2.34375	2.34%
physics	7	1.822916667	1.82%
artificial intelligence	6	1.5625	1.56%
mathematics	5	1.302083333	1.30%
gender-based research	5	1.302083333	1.30%
entrepreneurship and entrepreneurship	5	1.302083333	1.30%
computer science	5	1.302083333	1.30%
tourism	4	1.041666667	1.04%
supply chain	4	1.041666667	1.04%
statistics	4	1.041666667	1.04%
scientometrics	4	1.041666667	1.04%
energy	4	1.041666667	1.04%
life science	3	0.78125	0.78%
ethics	3	0.78125	0.78%
wine sector	2	0.520833333	0.52%
regional science	2	0.520833333	0.52%
psychology	2	0.520833333	0.52%

Category	Count (articles on this subject)	Percentage (count*100/total)	Percentage %
life science-biomedicine	2	0.520833333	0.52%
intelligent transportation systems	2	0.520833333	0.52%
economy	2	0.520833333	0.52%
chemistry	2	0.520833333	0.52%
biotechnology	2	0.520833333	0.52%
telecommunities	1	0.260416667	0.26%
sociology	1	0.260416667	0.26%
second language acquisition	1	0.260416667	0.26%
science research	1	0.260416667	0.26%
physical education	1	0.260416667	0.26%
nuclear science	1	0.260416667	0.26%
materials science	1	0.260416667	0.26%
life cycle research	1	0.260416667	0.26%
librarian research	1	0.260416667	0.26%
informetrics	1	0.260416667	0.26%
infometrics	1	0.260416667	0.26%
genomics	1	0.260416667	0.26%
food science	1	0.260416667	0.26%
fisheries	1	0.260416667	0.26%
evolutionary computation	1	0.260416667	0.26%
cyber-physical	1	0.260416667	0.26%
bio-technology	1	0.260416667	0.26%
biomedicine	1	0.260416667	0.26%
biology	1	0.260416667	0.26%
bio-informatics	1	0.260416667	0.26%
astrophysics	1	0.260416667	0.26%
astronomy	1	0.260416667	0.26%
astrobiology	1	0.260416667	0.26%
applied science	1	0.260416667	0.26%
agriculture	1	0.260416667	0.26%
	Total:384	**100**	**100%**

Source: own research

As we see in both Table 7 and Figure 4, the primary theme encompassing most articles is health medicine, with a total of 58 articles addressing this subject. Studies on scientific collaboration in this area refer notably to cancer (“Corroborating Social Media Echelon in Cancer Research" by Mehmood et al., 2018), cardiovascular issues (“Co-authorship Network Analysis in Cardiovascular Research Utilizing Machine Learning 2009–2019” by Higaki et al., 2020), osteoporosis (“Co-authorship Network Analysis of Iranian Researchers on Osteoporosis" by Khalagi et al., 2021), and coronavirus (“Bibliometric Analysis of Worldwide Coronavirus Research Based on Web of Science Between 1970 and February 2020" by Khalili & Sreekumar, 2021). The remaining articles discuss studies on other diseases, medical exams, or refer to medical journals or institutes.

The second most popular subject (22 articles) in the field of scientific collaboration networks is technology. Some of the most indicative articles are “Get into the Club: Positioning a Developing Country in the International e-Gov Research” by Cunha et al., 2017, which discusses e-government; “Knowledge Mapping of Research on Teachers’ Digital Competence in China: A Bibliometric Analysis Using CiteSpace” by Li & Tinmaz, 2024, which focuses on digital competency; “On the Co-authorship Network Analysis in the Process Mining Research Community: A Social Network Analysis Perspective” by HabibAgahi et al., 2022, which pertains to the mining process field; and “Proving Ground for Social Network Analysis in the Emerging Research Area “Internet of Things” (IoT)” by Mehmood et al., 2016, which covers the Internet of Things.

The third most popular subject with 22 articles is the environment. For instance, the article “When Disasters Strike Environmental Science: A Case-Control Study of Changes in Scientific Collaboration Networks” by Rotolo et al., 2019, examines the changes in scientific collaboration networks within the field of environmental science, specifically focusing on wetlands scientists publishing research related to the marshes of the Louisiana Gulf Coast. Another relevant article is “The Rise of Network Ecology: Maps of Topic Diversity and Scientific Collaboration” by Borrett et al., 2014, which investigates the structure, function, and evolution of ecological systems using network models and analyses. Generally, articles on this theme refer to ecosystems, industrial ecology research, environmental engineering, gas emissions, seismology, floristic and Phytosociology literature and various other environmental issues.

The next subject is engineering mechanics (16 articles refer to this theme). Some indicative articles are “Identifying major civil engineering research influencers and topics using social network analysis” by Afolabi et al., 2020 about major civil engineering research influencers and topics in Nigeria, “On giant components in research collaboration networks: Case of engineering disciplines in Malaysia” by Kumar & Jan, 2013, about research collaboration networks within four engineering disciplines in Malaysia: electrical and electronics, chemical, civil, and mechanical engineering and “Q-measures for binary divided networks: Bridges between German and English institutes in publications of the Journal of Fluid Mechanics” by Chen &Rousseau, 2008, focusing on the collaboration network between England and Germany in the field of fluid mechanics. Other issues refer to mechanical energy harvesting, graphene field, 'steel structure' field, to continuum mechanics and to research discipline of "steel structures

Government-institutions is the next theme with 14 articles. For instance, indicative article is “Comparative analysis of university-government-enterprise co-authorship networks in three scientific domains in the region of Madrid” by Olmeda-Gómez et al., 2008 about collaboration networks among universities, government entities, and private enterprises. Another one is “Progress in adaptive governance research and hotspot analysis: a global scientometric visualization analysis” by Zhao et al., 2024 about evolution and current state of adaptive governance research. “Topical connections between the institutions within an organization (institutional co-authorships, direct citation links and co-citations” by Bornmann & Leydesdorff, 2015, examining the institutions within an organization through co-authorships. In this theme, we include research about institutions, universities, governmental issues etc.

The next subject with 13 articles is management. Some indicative articles are: “Co-production in health policy and management: a comprehensive bibliometric review” by Fusco et al., 2020 about co-production in healthcare services, particularly focusing on its development and application within health policy and management, “Growth and structure of authorship and co-authorship network in the strategic management realm: Evidence from the Strategic Management Journal” by Koseoglu, 2016 about co-authorship networks in the field of strategic management, “Mapping the institutional collaboration network of strategic management research: 1980–2014” by Koseoglu, 2016 about collaborations in strategic management research. The rest of the articles follow roughly the same logic in the selection of topics like information technology, management business and management field, management and accounting sciences, Talent Management research.

The last subject that we will discuss is nanotechnology (with 10 articles). The rest of the subjects refer to less than 10 articles per subject. Some articles are: “Collaboration or funding: lessons from a study of nanotechnology patenting in Canada and the United States” by Tahmooresnejad & Beaudry, 2019, about collaboration between researchers on academic technological production, specifically in the field of nanotechnology, “How to identify research groups using publication analysis: an example in the field of nanotechnology” by Calero et al., 2006 about research groups in the field of nanotechnology, “The role of Chinese–American scientists in China-US scientific collaboration: a study in nanotechnology” by Wang et al., 2012 about scientific collaboration, specifically focusing on the field of nanotechnology.

After analyzing the main subjects of the articles, the sample size is also considered an important metric and analyzed below. The selected articles investigate different types of sample sizes, such as authors/researchers (about academic collaboration, productivity, networks of scientists to understand co-authorship networks), articles/publications (which focus on bibliometric analysis, topic trends, citation analysis to understand scientific productivity, domain evolutions, and impact), institutions/universities/departments (to understand collaboration patterns between unis or institutions, their research performance and contribution), citations/references (important for impact analysis and measuring the trends of a specific field), and patents/innovations (to study innovation and new trends) depending on the research needs.

All of them aim to examine the collaboration networks formed in each case. We can observe large, medium, and small sample sizes. Many articles have very large datasets. For example, “Multilayer representation of collaboration networks with higher-order interactions”, by Vasilyeva et al., 2021, examines 1,679,779 articles with 1,068,043 authors, “Global scientific collaboration: A social network analysis and data mining of the co-authorship networks”, by Isfandyari-Moghaddam et al., 2023 examines 10,460,999 documents for co-authorship analysis and 711,025 highly cited papers for collaboration pattern discovery and “Social Network Analysis of COVID-19 Research and the Changing International Collaboration Structure”, by Qin & Chen, 2024, examines 250,000 COVID-19-related academic publications. Regarding medium sample size, many articles examine less data. “Structure and collaboration relationship analysis in a scientific collaboration network”, by Hui et al., 2011, examines 7,343 authors contributing to 13,919 papers, and “Seismology as a dynamic, distributed area of scientific research”, by Wagner & Leydesdorff, 2003, examines 2,389 articles in geophysics. Finally, same articles examine small sample size. “Co-evolution of departmental research collaboration and scholarly outcomes”, by Katerndahl, 2012 examines 26 faculty members from a specific department and “Forging a link between mentoring and collaboration: a new training model for implementation science”, by Luke et al., 2016 examines 94 participants, consisting of 43 fellows, 9 core faculty, and 42 expert faculty members.

3.3. The use of Social Network Analysis in the context of scientific collaboration network and what the future holds for the field.

As we mentioned in the review protocol, we used specific keywords while searching in different databases. The search term is repeated here for convenience: (“scientific collaboration network” OR “scientific cooperative network” OR “scientific co-authorship network” OR “co-authorship network”) AND “social network analysis”. While searching about scientific collaboration networks we used the Boolean operator AND with the term “social networking analysis”. This means that we wanted to find articles about scientific collaboration networks that necessarily use social networking analysis and optionally additional methodologies.

After the full-text analysis of all 348 articles, we noticed that most articles combine social networking analysis with other methodologies, like combining traditional bibliometrics with computational techniques. By integrating social network theory, which is both a methodology and a theoretical framework (Wasserman & Faust, 1994; Newman, 2001) with statistics, machine learning, visualization etc., researchers in the field of scientific collaboration networks try to reveal collaboration patterns, collaboration dynamics, the most influencing actors, and of course make predictions of the field.

In the field of social networking analysis (which refers to the relation between nodes and edges), data science (which is a process of extracting information from data using statistics, algorithms, and programming, providing the tools to clean, and analyze data) (Hastie et al., 2009) and machine learning (where computers learn from data to predict for example the node behavior) (Raghu & Schmidt, 2020) are used as parallel methodologies and techniques.

We found articles that use *network construction*, which is a process of finding nodes and edges to construct graphs of co-authorship networks (for example "Trends in science networks: understanding structures and statistics of scientific networks" by Kas et al., 2012, and "The influence of academic advisors on academic network of Physics doctoral students: empirical evidence based on scientometrics analysis" by Wang et al., 2021). They construct co-authorship networks, citation networks, Bipartite networks, and Hypergraphs. *Data collection and processing* is also identified in articles, where researchers try to extract data from databases for bibliographic purposes, try to determine the identity of the authors, collect the publication records and handle the data for their purposes (for example, "Global trends and characteristics of nano- and micro-bubbles research in environmental engineering over the past two decades: A scientometric analysis" by Movahed & Sarmah, 2021 and "Co-Authorship Network Analysis in Industrial Ecology Research Community" by Kim & Perez, 2015).

We also notice the use of *descriptive analysis*, where authors use centrality measures, core-periphery analysis, and degree analysis. They try to identify the most influencing authors, institutions, universities, and which nodes are central within the network and understand how networks evolve or expand over time. For example, "Global trends in the scientific research of the health economics: a bibliometric analysis from 1975 to 2022" by Barbu, 2023 and "Co-authorship Networks in Left-Behind Children Research in China: A Social Network Analysis" by Luan et al., 2024, are some articles that use this methodology along with SNA.

We noticed that *statistical analysis-modeling* is also prominent in our data. Researchers apply logistic regression to find and predict collaboration patterns. They specifically apply Poisson/negative binomial regression based on the number of publications or citations to study the relationships in the network, and structural equation modeling to examine complex relationships between variables. For example, "The science network in Italian population research: An analysis according to the social network perspective" by Rivellini et al., 2006 and "Bidirectional relationship between network position and knowledge creation in Scientometrics" by Guan & Pang, 2018, are some articles that use the above methodologies along with SNA.

Longitudinal analysis also is prominent in our data collection, where researchers study how networks evolve, the phases and the trends of the networks and the changes in their structure. Techniques used in our data are: Stochastic Actor-Oriented Models, Time-series segmentation, and blockmodeling. Example from our data: "On the dynamics of national scientific systems" by Doreian et al., 2011 and "Co-authorship networks in business ethics: A longitudinal study" by Koseoglu et al., 2018.

Machine Learning and AI is also used (Topic modeling, Link prediction, Agent-based modeling) where researchers group articles and sample themes automatically to identify collaborations that may occur in the future and examine the dynamics of the networks (simulation): "Topic scientific community in science: a combined perspective of scientific collaboration and topics" by Mao et al., 2017, and "Women and key positions in scientific collaboration networks: analyzing central scientists' profiles in the artificial intelligence ecosystem through a gender lens" by Hajibabaei et al., 2023.

Other methodologies and techniques used are *community detection* (like Hierarchical clustering and Louvain/Newman-Girvan algorithms) for grouping and clustering of the data; *visualization and mapping* (using Science mapping like VOSviewer and CiteSpace) for visualization of the networks (like disambiguation protocols, reliability simulations, Jaccard/affinity indices) with the intent of testing the robustness of the network, or *hybrid methods* (NPR matching, SEIRS for knowledge diffusion). Some examples of our dataset are "Community Structure and the Evolution of Interdisciplinarity in Slovenia's Scientific Collaboration Network" by Luzar et al., 2014, "Measuring science–technology interactions using patent citations and author-inventor links: an exploration analysis from Chinese nanotechnology" by Wang & Guan, 2011.

Besides the various methodologies and techniques, SNA is observed in all 348 articles. However, the question is how social networking analysis is used in all these cases. As a methodological framework, SNA is used to examine the relation between different kinds of entities. Researchers use SNA to examine authors, institutions, universities, countries, and their relations and interactions to create networks. In our dataset, we observe many kinds of networks, like co-authorship networks, institutional/university networks, country networks, where researchers create networks of nodes (universities, countries, institutions, and mainly authors) and edges (co-authored papers, publications between authors from different countries). They want to find research communities, analyze different metrics of their network (like density, weight), examine the relationship that different countries or institutions create by co-authored papers, and detect central actors (in our data USA, and China have a dominant position). To find central actors, they apply different centrality measures, like degree, betweenness, and closeness centrality. The aim is to find the most central, influential actors in the network, like prominent authors, institutions, and countries. Using SNA researchers discover the way knowledge is spread in different networks, identify the trends in different scientific fields, detect clusters of papers that are usually cited together, and find those papers that attract scientific attention or cause a trend in a field.

It's also important to mention that researchers apply SNA to evaluate the impact and the productivity, considering the citations, the position in the network (like using H-index and centrality measures). It is useful to compare different nodes like universities, authors, and departments to find their research impact. Many researchers use SNA to find the trends in a field and evaluate or even predict the future in collaboration communities. They usually use longitudinal analysis, link prediction, machine learning, etc. Some articles use SNA to uncover inequities in different research fields. Some use SNA to identify the differences between genders in the scientific communities (gender-based analysis) and to detect the marginalized actors (core-periphery analysis). Usually, female scientists have fewer opportunities and are less connected in the communities. And finally, they use SNA to visualize all these networks of actors and their relationships (using Gephi, VosViewer). By visualizing all these communities, researchers reveal the structure of the field.

In general, the field of scientific collaboration networks seems to be evolving. Based on our dataset, we can assume certain key elements about scientific collaboration networks after reading all the 348 articles. There is increased interest in scientific collaboration networks in many scientific disciplines. There is a trend toward multi-authored articles, where researchers try to collaborate rather than publish an article alone (for example, in studies about finance, economy, etc.). There is an important flow of knowledge across many disciplines and due to globalization, scientific collaboration between different countries around the world is further facilitated. Some countries like China, the USA, and the UK play a key role in global scientific collaboration. Additionally, we observe some differences across different disciplines. For example, natural sciences tend to have denser networks than social sciences, health medicine occupies many researchers, especially from the USA and EU, and the field of technology and sustainability also has significant growth (mostly in China and Western nations). Studies about gender reveal that men have a prominent and a more central position in networks than women. Regarding the quality of the collaboration, it seems that multi-authored papers are highly cited by other researchers. Also, papers that try to connect different groups tend to be more innovative (like in nanotechnology). Based on our dataset we see that in each collaboration network there are always some nodes/actors that are more prominent and some less central. For example, Harvard as a university and the USA, UK, and China as countries are more dominant. Regarding the geographical distribution of collaboration networks, we observe that certain countries are the dominants, like Canada, USA, UK, China, India, Brazil, and South Africa either in density or in volume. Also, countries tend to collaborate with the nearest countries, due to proximity. We can also observe that institutions or universities tend to collaborate more or trigger collaboration more than the government, which promotes collaboration in hard sciences mostly.

As we see, the field of scientific collaboration networks is still evolving and attracting the interest of researchers in different disciplines around the world, remaining open to innovation and new ideas. Our research reveals some aspects that are still open to investigation in the field of scientific collaboration networks. First, it looks like North America, Europe, and China get disproportionate attention compared to lesser-known regions like Greece so the focus of new research could shift to those regions that have been left out so far. Also, some regions are more resistant than others to collaborations with disjointed nodes cropping up. Similarly, collaboration networks are more likely to appear in certain scientific fields, like physics, than in others, like economics. This disparity in collaboration likelihood, regardless of if it is across regions or scientific fields, requires further research.

Another gap pertains to gender. Women seem to be underrepresented compared to men in our sample which calls for further examination on the reasons behind this. Also, it is important for researchers to study core-periphery actors and possibly identify factors that play into the centrality of certain nodes. We can also observe gaps regarding the methodology, like the need to introduce new metrics besides the traditional centrality metrics.

Greece only moderately appears in the studies in our sample which shows how understudied collaboration networks are in the region. Greek researchers tend to collaborate mainly with other European researchers (like Italians, Germans) in funded projects from the European Union in scientific areas like medicine, biomedical, marine, physics, engineering, clinical research, and more rarely in social sciences. They try to collaborate with researchers abroad to strengthen their international relationships. We also observe that in Greece some institutes/universities have a key role in these networks, like the University of Athens, and the Aristotle University of Thessaloniki. To the best of our knowledge, there is no study about other Greek researchers from other Greek universities. Greece has 25 universities and there is no study about the scientific collaboration of Greek researchers in these institutes. A few studies study Greek scientific productivity but do not explore collaboration networks. Maybe the scientific output of Greek researchers is small compared to the global scientific output, or maybe the interest of the research is still focused on bigger countries. It would be interesting to find a collaboration and quality index of Greek universities, which could later become a case study for other countries of similar size.

4. Conclusions

In this systematic literature review, we provided an overview of scientific collaboration networks through the lens of social networking analysis, in various scientific fields. In this SLR we tried to answer three research questions by studying articles from selected databases from 1984 onwards. Following the processes described in the review protocol, we ended up with 348 related articles related to our subject. The rest of the articles from the four selected databases were eliminated because they did not fulfill the inclusion criteria. Based on these articles, we tried to describe the evolution of scientific collaboration networks through the years, the publication trends, the collaboration and structural patterns, influential actors, and dynamics of the field, the focus of the literature on scientific collaboration networks, and finally, the methodologies combined with SNA in all these selected articles.

The analysis revealed that the scientific community studied scientific collaboration networks across various perspectives, topics, and disciplines, including health-medicine, economics, engineering mechanics, social sciences, environment, technology, and many more. Most of the articles focus on health, medicine, technology, and environmental issues. In the process of the full-text analysis of the articles, we observed that samples vary from authors, institutions, universities, to countries, and citations. Researchers try to uncover new trends, collaboration, structural patterns, influential actors, peripheral or neglected actors, and the dynamics of the field, via various techniques and methodologies, including SNA. Other methodologies or techniques used are network construction, descriptive analysis, statistics, longitudinal analysis, Machine Learning and AI, and community detection. As we see, there is methodological diversity. Researchers combined SNA with various other techniques to analyze the structure, the metrics, and the dynamics of the networks.

The present study has some limitations. The review was specific on the type, the language, and the databases during the search process. We chose to study only articles, written in English, in Scopus, Web of Science, Science Direct, and Springer Link Nature. We also studied these articles according to the research questions we presented above. Future studies could broaden their focus on more types of papers, on more languages, on more databases, or even search for other aspects when studying their dataset. As we mentioned in the results section, due to the authors' origin, we see opportunities to study scientific collaboration networks in underrepresented countries or regions, like Greece, to broaden the field. We also observed that most of the studies were focused on specific subjects or themes, rather than adopting a more general approach. For example, while many analyze scientific collaboration networks within specific research domains, few explore such networks at a national level. Finding collaboration patterns between scientists of a country could yield interesting insights, which could be used to evaluate institutional productivity or identify quality indicators. This field remains open to further exploration and innovative research directions.

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