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MODELE I WYZWANIA PROJEKTOWANIA SIECI PRODUKCYJNYCH Z PUNKTU WIDZENIA UKŁADÓW CYBER-FIZYCZNYCH

Streszczenie: Celem pracy jest badanie najnowocześniejszych modeli i metod stosowanych w projektowaniu sieci produkcyjnych. Do metaanalizy wykorzystano prace wybrane z Web of Science. Analizę przeprowadzono przy pomocy podejścia opartego na grafach oraz oprogramowania CiteSpace.

Słowa kluczowe: projektowanie sieci produkcyjnych, układ cyberfizyczny, CiteSpace.

MODELS AND CHALLENGES OF MANUFACTURING NETWORK DESIGN FROM VIEWPOINT OF CYBER-PHYSICAL SYSTEMS

Summary: The purpose of the work is to study state-of-the-art models and methods applied in manufacturing network design. For the purpose of meta-analysis the work collected from Web of Science were used. The analysis was implemented with the help of graph-based approach and CiteSpace software.

Keywords: manufacturing network design, cyber-physical system, CiteSpace

1. Introduction

In the ever-evolving landscape of modern industry, the concept of Manufacturing Network Design has emerged as a pivotal strategic component for organizations seeking to optimize their production processes, enhance efficiency, and remain competitive in a global marketplace. This discipline represents the systematic and holistic approach to structuring and managing the interconnected web of facilities, suppliers, distribution centers, and information flows that make up a manufacturing network [1].

Manufacturing Network Design is not a static endeavor but rather a dynamic and continuous process that aligns a company's manufacturing capabilities with its business goals. This process making critical decisions related to location, capacity,

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logistics, and technology deployment within a network, all while considering factors such as cost, quality, speed, and flexibility [2].
Manufacturing Network Design plays a pivotal role in enabling organizations to compete effectively in an increasingly complex and interconnected global economy [3].
The logistical aspect of Manufacturing Network Design presents a set of complex challenges and considerations that organizations must address to ensure the efficient operation of their manufacturing networks [4].
During Manufacturing Network Design, logistics problems often arise, which include such points as determining the most profitable places for the placement of production facilities, warehouses, and distribution centers to reduce transportation costs, reduce delivery times, and efficiently meet the needs and requests of consumers. Integrating suppliers, manufacturers, and distributors into a single supply chain, network ensures the efficient and cost-effective movement of materials and products on time, finding the right balance between having sufficient inventory to meet customer needs and striving to reduce running costs and excess inventory levels. Also, the selection of the most economical and environmentally friendly methods of transportation and routes of movement of goods in the network and accurate forecasting of consumer demand optimizes production schedules and prevents situations of either overproduction or shortage.
Logistics risks such as supply chain disruptions, transportation delays, or inventory shortages, use warehouse management systems (WMS), transportation management systems (TMS), and Internet of Things (IoT) devices to improve visibility and control over logistics processes.
Effective managing the flow of goods in the reverse direction, including returns, recycling, and disposal, is a cost-effective and environmentally responsible way, and establishes strong relationships with suppliers to ensure a constant and reliable flow of materials and components into the network.
Balancing cost-effectiveness with the ability to provide customers with fast and efficient service, includes order fulfillment and delivery, and addressing the inherent logistical challenges of expanding production networks in international markets, including issues such as customs, tariffs, and cultural differences.
Resolving these logistical challenges in the realm of Manufacturing Network Design necessitates a comprehensive approach that considers the entire supply chain, from raw materials to end consumers. This frequently involves utilizing advanced technologies, data analysis, and collaboration with various stakeholders to optimize logistics processes, reduce costs, and enhance customer satisfaction.
The objective of the work is to investigate and summarize the state-of-the-art problems of manufacturing network design based on meta-analysis of the current research in the field and applying graph-based approach.

2. Material and methods

2.1. Web of Science

Web of Science is a comprehensive and widely used research database and citation index that provides access to a vast collection of scholarly literature across various disciplines. It is a valuable tool for researchers, academics, and professionals seeking access to high-quality research papers, articles, conference proceedings, and citation data [5].

Users can perform advanced searches using keywords, authors, institutions, publication titles, and more. The platform offers robust search and filtering capabilities to help users find relevant research efficiently.

To carry out an analytical review of Manufacturing Network Design, a query was constructed in the form:

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TS=("manufacturing") AND TS=("network") AND TS=("design")
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2.2. CiteSpace

CiteSpace offers various export options to save your findings and visualizations. You can save network graphs, clusters or data for later analysis and presentation.

There are general guidelines for using CiteSpace. Specific features and options may vary depending on the software version and your research needs. It is important to refer to the official documentation or user guides [6-12] provided by CiteSpace for detailed instructions and to adapt these steps to your specific research project.

3. Results

3.1. Cluster analysis of keywords

The network consists of 6 highlights major clusters. The largest 6 clusters are summarized as follows. See an overview of the network on Figure 1.

Cluster #0 “cloud manufacturing” covers the literature on self-organizing manufacturing systems (SOM) and presenting the complete concept of self-organized manufacturing network (SOMN) as a next-generation manufacturing automation technology to achieve mass customization and a global manufacturing business process network (GMBPN). They are constructed according to the input and output relationships of manufacturing business activities. The comprehensive industrial ecosystem is oriented on the networked collaborative manufacturing platform (NCMP). There was described a comprehensive model when is adapted to a global electrical medical device manufacturing system. The elevated number of manufacturing solutions was offered via cloud platform to connected customers. The system framework of NCMP is based on three chains (manufacturing chain, value chain, and industrial chain).

This cluster includes 65 participants. The major citing article of the cluster is [13]. The most cited members in this cluster are [14-16].

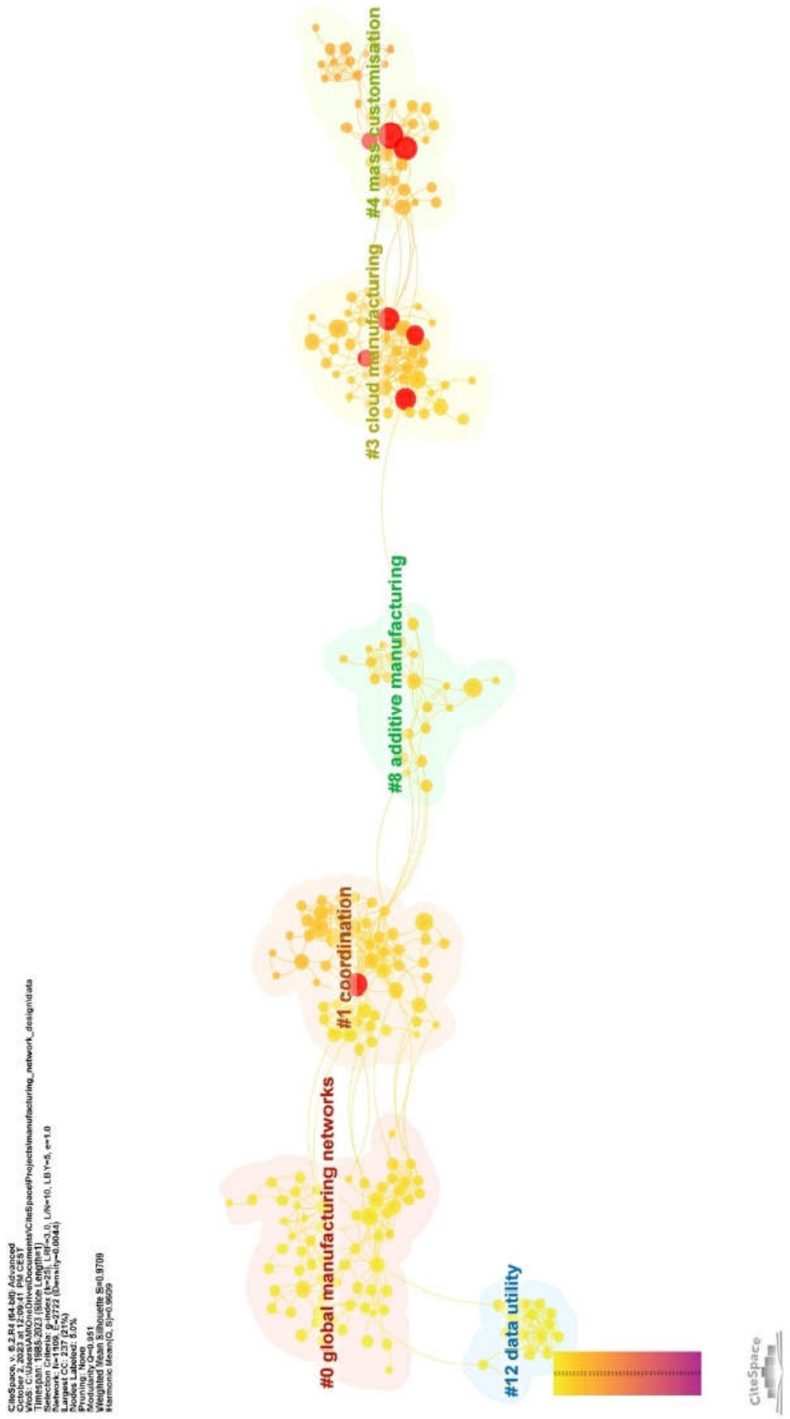

Figure 1. An overview of the network

Cluster #1 “manufacturing network strategy” describes the development of a process for manufacturing network strategy deployment. Research on the relationship between strategic targets of manufacturing networks and their fulfilment are presented. The use of cloud environments to integrate distributed manufacturing facilities and entirely control the production processes was studied. Modeling and simulation of large, distributed manufacturing and networks to optimize mechanical and manufacturing processes using radio frequency identification (RFID) technology are considered. Research on whether the production specializations of network factories performing similar strategic roles of factories are common in type is shown. Designing, developing production networks, and achieving transparency through different levels of analysis is studied. Process for the strategic management of a manufacturing network, integrated decision-making process for the design and management are defined by digital manufacturing technologies. This cluster includes 55 participants. The major citing article of the cluster is [17]. The most cited members in this cluster are [18-20].

Cluster #3 “mass customization” is describing C3DP task modeling for a complex network model established based on the dynamic coupling of nodes, taking cloud manufacturing resource characteristics such as distribution and diversity into account. A new method for manufacturing resource supply-demand matching based on complex networks and internet of things (IoT) is proposed. Architectural analysis, synthesis, and evaluation steps for IoT-enabled intelligent process-aware cloud production platforms were implemented. An algorithm to analyze the context information of equipment and human body motion based on a variety of sensor input information in the cognitive manufacturing process is offered. Model is based on cloud tasks and services.
This cluster includes 43 participants. The major citing article of the cluster is [21]. The most cited members in this cluster are [22-24].

Cluster #4 “manufacturing network” involves a mass customization and personalization implementation, by engaging the customer in the design of unique products and by enabling the original equipment manufacturers (OEMs) and a sets of potential central distribution centers (CDCs). The uncertain environment is modelled by introducing perturbations in demand. The robustness of networks is considered as a function of network size. Alternative manufacturing network configurations are studied. An intelligent method that utilizes three adjustable control parameters and can be used for the identification of efficient globalized manufacturing network configurations capable of carrying out the production of mass customized products was developed.
This cluster includes 36 participants. The major citing article of the cluster is [25]. The most cited members in this cluster are [26-28].

Cluster #8 “mesoscale lattice structure” is focusing on additive manufacturing and optimization of piping network in compact system. A hybrid decomposition algorithm, combining the sample average approximation algorithm with an adaptive large neighbourhood search algorithm is presented. There was considered the aerospace sector as a source of competitiveness and innovation with great technological development capacity. The phases of the MSLSS design process are

shown. A novel optimization framework that simultaneously considers interdependence of flow networks, resource restrictions, and process-and-system level costs under a unified decision framework for the design and management of an integrated additive manufacturing (AM) supply chain network was studied.
This cluster includes 22 participants. The major citing article of the cluster is [29]. The most cited members in this cluster are [30-32].
Cluster #12 “role” is devoted to achieving cognitive mass personalization via the self-x cognitive manufacturing network. An industrial knowledge graph- and graph embedding-enabled pathway were used.
This cluster includes 16 participants. The major citing article of the cluster is [33]. The most cited members in this cluster are [34-36].

3.2. Burstness

This analysis shows us the works with the exponential growth of the citation. It allows us to determine the most significant directions in the branch. The historical view of the bursts is presented on Fig. 2, where together with the strength of the burstness, bursting period is displayed.

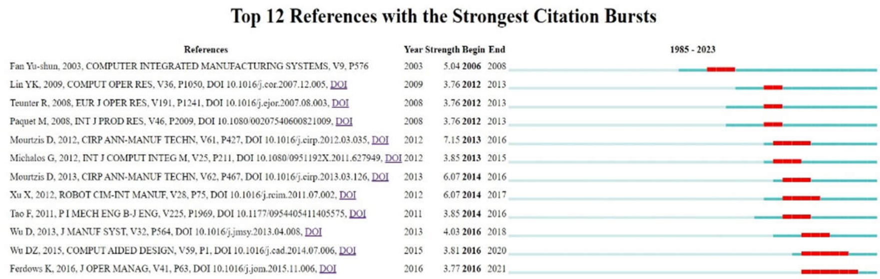

Figure 2. Top 12 References with the Strongest Citation Bursts

3.3. Timelines

According to the methodology, 1006 articles and reviews were found as part of the search strategy. The number of published articles and their variations indicate the rate of growth of interest in this field and the obvious progress.
According to the search results, articles published on the topic of “Manufacturing network design” were divided into the following phases, namely, a steady progress phase between 1988 and 2003 and a rapid growth phase between 2004 and 2023.
The phase of stable progression indicates a stable number of annual literature publications on the topic “Manufacturing network design”. The phase of rapid growth indicates an increase in publications on the topic “Manufacturing network design” from year to year. Although fewer articles were published in individual years from 2005 to 2008, 2011 and 2020, this did not affect the development of the topic.
In cluster #0 “global manufacturing networks”, the development of literature and an increase in the number of publications has been observed since 2004 and continues until 2022, with the largest number publications in 2018. In cluster #1 “coordination”, the development of literature and an increase in the number of

publications is observed from 2010 to 2020, with the largest number publications in 2013. In cluster #3 “cloud manufacturing”, the development of literature and an increase in the number of publications is observed from 2010 to 2020, with the largest number of publications from 2012 to 2014. In cluster #4 “mass customization”, the development of literature and an increase in the number of publications is observed from 2005 to 2014, with the largest number publications in 2009. In cluster #8 “additive manufacturing” the development of literature and an increase in the number of publications is observed from 2011 to 2017, with the largest number publications in 2016. In cluster #12 “data utility” the development of literature and an increase in the number of publications is observed from 2017 to 2022, with the largest number publications in 2018. (Fig. 3, Fig. 4)

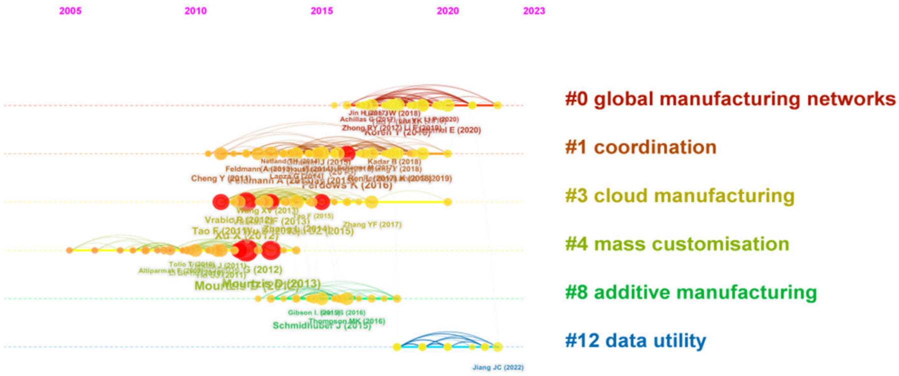

Figure 3. Timeline graphs with the respect to keyword clusters

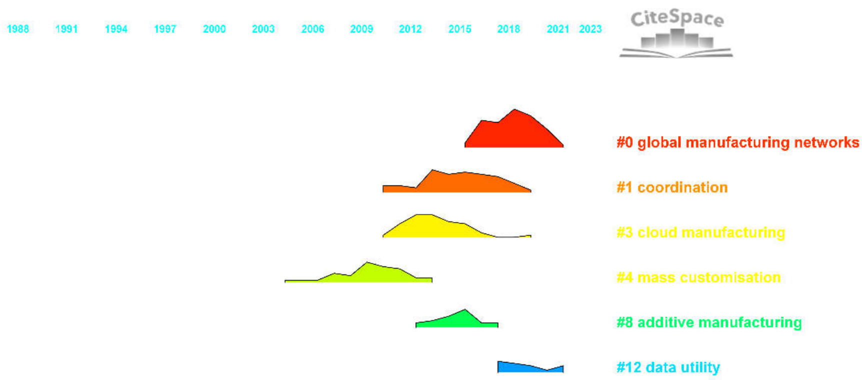

Figure 4. Timeline histograms with the respect to keyword clusters

3.4. Author analysis

An analysis of authors by the number of publications by cluster was carried out. Each node is labeled by the corresponding author, and the linkage between the two nodes indicates that the two authors cooperated to conduct the research (Fig. 5 and Fig. 6).

The most productive author was Cheng Y, Shi Y in cluster #2 “global manufacturing networks”; Chryssolouris G, Mourtzis D, Koren Y in cluster #3 “mass customization”; Xu X, Schuh G, Wang Y, Ren L in cluster #1 “intelligent manufacturing”; Kusiak A in cluster #5 “fuzzy set theory”; Zhank YF in cluster #0 “cloud manufacturing”; Lee H, Listes O in cluster #6 “system reliability”.

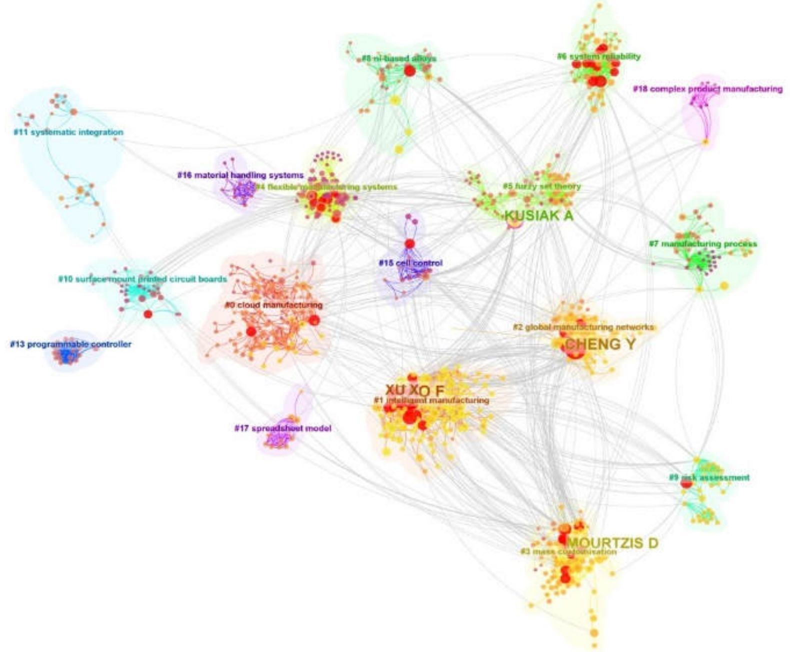

Figure 5. Network for the author analysis

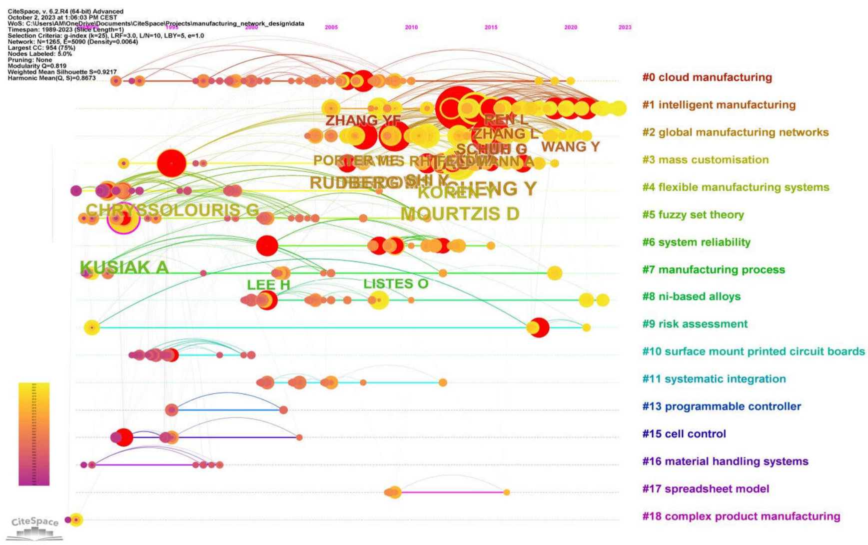

Figure 6. Timeline of the authors with the respect to keyword clusters

The Top 59 cited authors with the largest number of citations are highlighted. The most cited author is Cheng Y with the largest burst of citations in 2015, Tao F with the largest burst of citations in 2013, Chryssolouris G with the largest burst of citations in 2011.

3.5. Leading organizations and countries

The literature analysis was carried out by institutions according to the number of publications and the clusters to which they belong. The largest organizations by number of articles are Hong Kong Polytechnic University, Huazhong University of Science & Technology University, National University of Singapore in cluster # 0 “orthogonal experimental design”; RWTH Aachen University, University of Patras, Lund University in cluster # 1 “coordination”; Guizhou University, Zhejiang University in cluster #2 “electronic assembly”; Georgia Institute of Technology, University System of Georgia em of Florida in cluster #3 “petri nets”; Pennsylvania State University – University Park, State University of New York (SUNY) System, SUNY Buffalo in cluster #4 “engineering informatics”; Beihang University in cluster # 5 “smart manufacturing” (Fig.7 and Fig. 8)

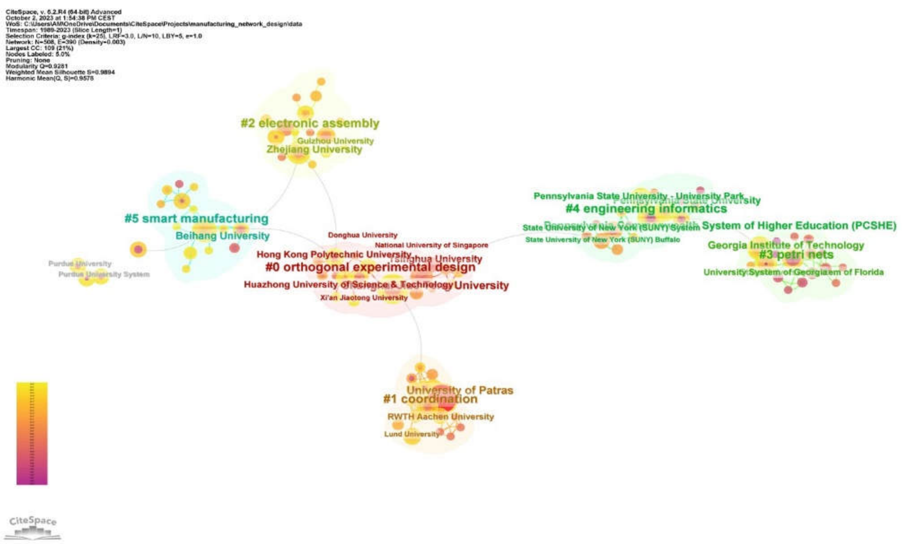

Figure 7. Network of the organizations

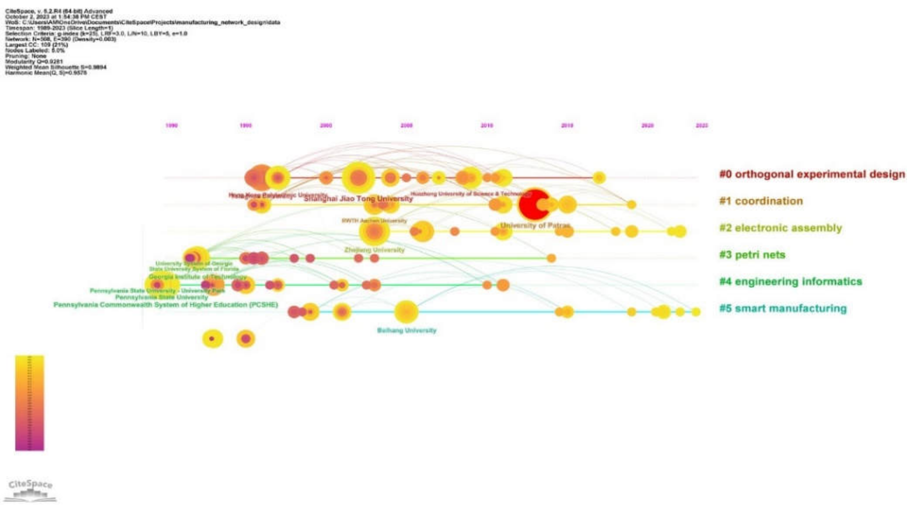

Figure 8. Timeline of organizations clustered from the viewpoint of keywords

The Top 4 institutions with the strongest citation bursts. The biggest outbreak of publications in University of Patras in 2013, with bursts of 7.52. The next in number of publications are Northeastern University – China in 2006, with bursts of 7.04, Rensselaer Polytechnic Institute in 2001, with bursts of 4.39, National Taiwan University of Science & Technology in 2002, with bursts of 3.65.

Top 4 Institutions with the Strongest Citation Bursts

Institutions	Year	Strength	Begin	End	1989 - 2023
Rensselaer Polytechnic Institute	2001	4.39	**2001**	2005	
Northeastern University - China	2006	7.04	**2006**	2009	
National Taiwan University of Science & Technology	2002	3.65	**2012**	2013	
University of Patras	2013	7.52	**2013**	2016	

Figure 9. The Top 4 institutions with the strongest citation bursts

An analysis of 508 countries was carried out and 6 countries were selected, which provided the largest number of articles. Such countries are England and Germany in cluster #0 "case studies", Peoples R China, Greece in cluster #1 "global production networks", USA in cluster #2 "supply chain design", Canada, India in cluster #3 "wastes". (Fig. 10)

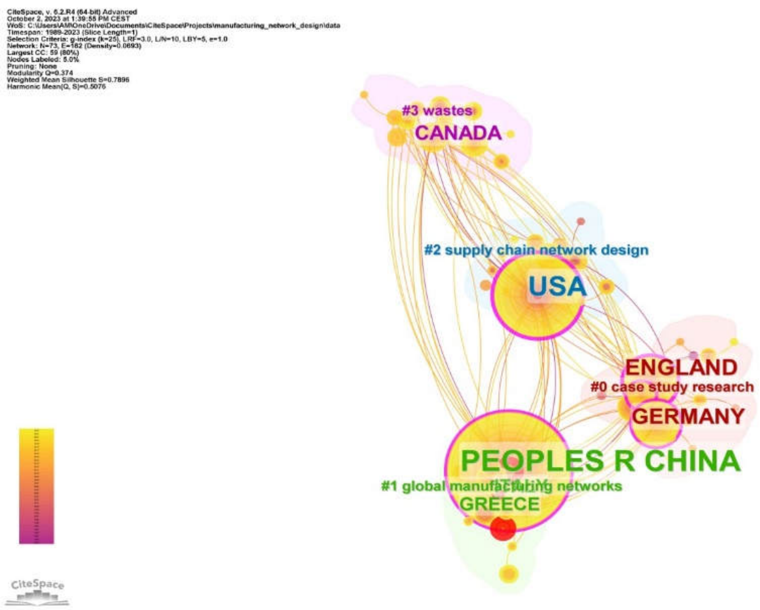

Figure 10. Network of the countries

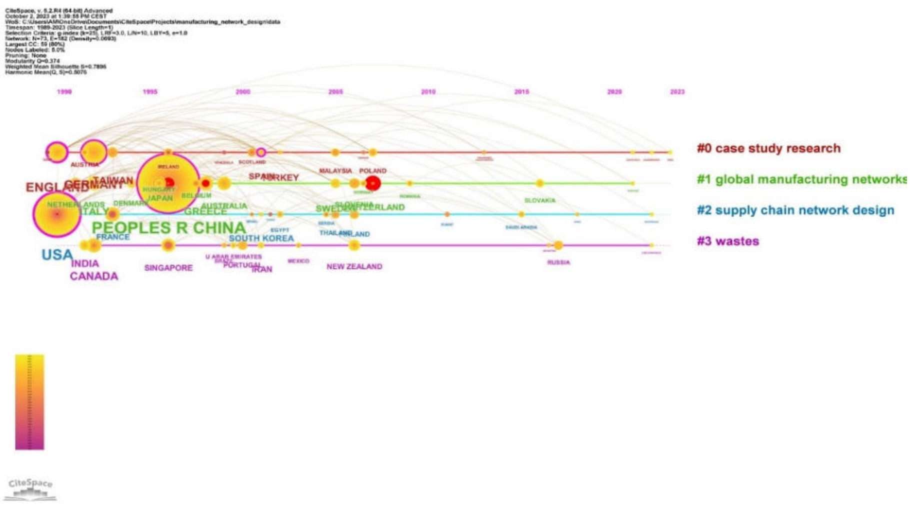

Figure 11. Timeline of countries clustered from the viewpoint of keywords

Top 5 countries with the strongest citation bursts. In first place is the USA with the biggest surge in 1990. The following countries: China with the largest spike in 1996, Greece with the largest spike in 1998, England with the largest spike in 1990, Switzerland with the largest spike in 2007. (Fig. 12)

Figure 12. Top 5 countries with the strongest citation bursts

4. Conclusions

For the reason given above, a comprehensive analysis in the field of manufacturing network architecture design was conducted. It allowed us to study the main branches of Manufacturing Network Design. On the other hand, the leading authors, institutions, and the countries. Together with determining the most perspective issues we have obtained the historical view of the research area.

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