ESTABLISHING COLLABORATIVE RESEARCH NETWORKS: A LITERATURE REVIEW

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Abstract

This study delves into the complex dynamic within collaborative research networks (CRNs), with the aim of examining theoretical perspectives and common issues within the existing literature. CRNs have emerged as crucial mechanisms for addressing complex scientific challenges, fostering interdisciplinary collaboration, and enhancing knowledge dissemination. Through a comprehensive analysis, this review provides valuable recommendations for policymakers, academic institutions, and researchers seeking to establish and nurture successful collaborative research networks. Through synthesizing insights from various scholarly articles, we explore the components, mechanisms, practices, challenges, and opportunities encountered within CRNs bolstered by digital technologies and innovative practices, and their impact on sculpting the future landscape of manufacturing, technology transfer, and enhancing organizational performance. The article concludes with recommendations for future research directions, emphasizing the need for further exploration of CRNs' long-term impacts on the scientific community and society at large, addressing a notable gap for robust frameworks and practical guidelines essential for the effective development and implementation of CRNs.

Keywords: Literature review, Collaborative research, Networks, Innovation, Framework

JEL Classification: O32 Management of Technological Innovation and R&D

1. Introduction

In the current era, marked by rapid technological advancements and a pressing need for innovative solutions to complex global challenges, CRNs have emerged as vital platforms for facilitating interdisciplinary and cross-sectoral cooperation. However, the absence of a standardized or universally adopted framework for managing these collaborations often leads to inefficiencies, misunderstandings, and missed opportunities.

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In recent years, research has begun to delve deeply into how networks behave, evolve, and influence various phenomena, from biological systems to social networks and urban infrastructures. Theories presuppose an interaction between individuals and their networks, focusing on their relationships and structures, with many different theoretical concepts defining networks [1].

Numerous types of networks are identified: internet, industrial, social, scientific, organizational, transportation, electrical energy, distribution, telecommunication, trophic, neural, aerial, linguistic, etc., they are represented by graphs. The advent of the Internet has led to an exponential increase in the ways people can connect and has brought about essential changes in the way information is circulated and relationships are formed.

Most businesses that cooperate with higher education institutions that are also research and development (R&D) institutions also collaborate with other businesses or have their own R&D capabilities [2]. Collaboration in research plays a fundamental role in encouraging valorization activities and increasing the innovation capacity of organizations. Through partnerships between universities, research institutes, companies, and other entities, the exchange of knowledge and technologies is facilitated, accelerating the transfer of innovations from the research stage to the market.

As noted in an OECD study [3], collaborative scientific research platforms face a series of issues: the need for a robust data infrastructure, global material data management, the existence of scalable data repositories, and the implementation of efficient data cleaning strategies; lack of coordination, redundancy, or dispersion of equipment and technical expertise; the need for interdisciplinary research, development, and training; the absence of ecosystems that facilitate the building of new supply chains. Therefore, valorization activity, defined as the process of transforming research results into tangible benefits, is closely linked to innovation capacity, and both are enhanced through strategic and efficient collaborations in research.

The industry is increasingly moving towards an open innovation process, which includes collaboration with other businesses and higher education institutions, recognizing the value brought by this collaboration. Collaboration in the field of research plays a fundamental role in encouraging valorization activity and in increasing the innovation capacity of organizations. Through partnerships between universities, research institutes, companies, and other entities, the exchange of knowledge and technologies is facilitated, accelerating the transfer of innovations from the research stage to the market.

Sharing research resources through platforms optimizes the use of expensive equipment and specialists' time, encourages intercultural collaboration in research, promotes the adoption of open and universal formats for data storage and transmission, and facilitates access to cutting-edge technologies and equipment, involving all participants in collaborative studies [4].

The aim of this study is to enhance the methodological framework of collaborative research network systems and to outline directions and strategies for boosting the synergistic development of industrial innovation and collaborative ecosystems. We set to explore the components, mechanisms, and practices within CRNs, aiming to identify and analyze CRNs and their characteristics, examine the challenges and opportunities encountered by scientific literature tackling collaborative research networks and evaluate the benefits and outcomes of CRNs.

By addressing our objectives, we intend to add to the body of work by proposing guidelines and recommendations for the development and implementation of CRNs for further research. The research questions below have emerged:

1. What are the main barriers and opportunities to effective collaboration in the context of CRNs?

2. What models or frameworks for CRNs have demonstrated success in overcoming these barriers, and what can be learned from them?

2. Research Methodology

2.1. Research design

The research method deployed of content analysis was useful for detecting theoretical perspectives and common issues within the existing literature regarding collaborative research networks. This research used a semi-systematic literature review methodology, as it is best suited to our research objectives. The method used to analyze and synthesize the findings from the review was content analysis as it can be broadly used for identifying, analyzing, and reporting patterns related to our research questions.

2.2. Data collection

To ensure the validity of the study, the Web of Science database was selected as it is one of the largest databases of the relevant scientific and research literature. Because of its diverse and inclusive nature, Web of Science can ensure that a large number and a broadened perspective on collaborative research networks is captured, and that state-of-the-art findings and emerging topics are reviewed.

Inclusion criteria for the review was guided by the selected research questions. The search within the database was performed by a Boolean expression applied in terms of the title, abstract and keywords of papers: TITLE-ABS-KEY (collaborative AND research AND networks) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (LANGUAGE , "English")) for the time span of 2020-2024.

The initial search on Web of Science, performed on the 15th of March 2024, was thus limited to Engineering Multidisciplinary, Engineering Industrial, Engineering Manufacturing and English, for the period 2020-2024, and it produced 881 results. As the initial literature searches yielded many articles, a strategy was needed to identify which are relevant. In terms of research quality, we decided on exclusion criteria based on (engineering industrial) – this produced 330 results.

We decided to further refine our search on exclusion criteria based on (industry innovation and infrastructure) which produced 75 results, and finally (open source) which produced 19 results, presented in the table below.

Article Title & Authors	Publication Year
"Micro dynamics and macro stability in inventor networks" Fritsch M. et al. [5]	2022
"A complexity assessment framework with structure entropy for a cloud-edge collaborative manufacturing system" Li, JJ. et al. [6]	2023
"Exploring self-organization and self-adaption for smart manufacturing complex networks" Guo, ZG. et al. [7]	2023
"Commercialization networks in emerging technologies: the case of UK nanotechnology small and midsize enterprises" Salehi, F. et al. [8]	2022
"Collaborative innovation in emerging innovation systems: Evidence from Central and Eastern Europe" Stojcic, N. et al. [9]	2021
"Collaborative modes with Cultural and Creative Industries and innovation performance: The moderating role of heterogeneous sources of knowledge and absorptive capacity" Santoro, G. et al. [10]	2020
"Innovation and innovator assessment in R&I ecosystems: the case of the EU Framework Programme" Nepelski, D. et al. [11]	2021
"Design Decisions and Interactions: A Sociotechnical Network Perspective" Pirzadeh, P. et al. [12]	2021
"Collaboration in BIM-based construction networks: a qualitative model of influential factors" Oraee, M. et al. [13]	2022
"Collaborations for Digital Transformation: Case Studies of Industry 4.0 in Brazil" Rocha, C. et al. [14]	2023
"Promoting academic engagement: university context and individual characteristics" Zhao, ZY. et al. [15]	2020
"Blockchain-based Shared Additive Manufacturing" Lupi, F. et al. [16]	2023
"Exploring dyadic relationships between Science Parks and universities: bridging theory and practice" Löfsten, H. et al. [17]	2024
"The effectiveness of interactive virtual reality for furniture, fixture and equipment design communication: an empirical study" Prabhakaran, A. et al. [18]	2021
"FLEAM: A Federated Learning Empowered Architecture to Mitigate DDoS in Industrial IoT" Li, JH. et al. [19]	2020
"Open data for open science in Industry 4.0: In-situ monitoring of quality in additive manufacturing" Gronle, M. et al. [20]	2023
"Developing distributed manufacturing strategies from the perspective of a product-process matrix" Kumar, M. et al. [21]	2020

"Impact of the changing business environment on performance measurement and management practices" Nudurupati, SS. et al. [22]	2021
"Buyer-supplier collaboration during emerging technology development" Moradlou, H. et al. [23]	2022

Table 1. Web of Science research articles results based on our inclusion and exclusion criteria.

3. Research Results

The researched articles provide in-depth information about collaborative research on a diverse range of contexts, including inventor networks, cloud-edge collaborative manufacturing systems, smart manufacturing, commercialization networks, collaborative innovation, and digital transformation in various sectors. The highest occurrence keywords resulting in our selected articles are below.

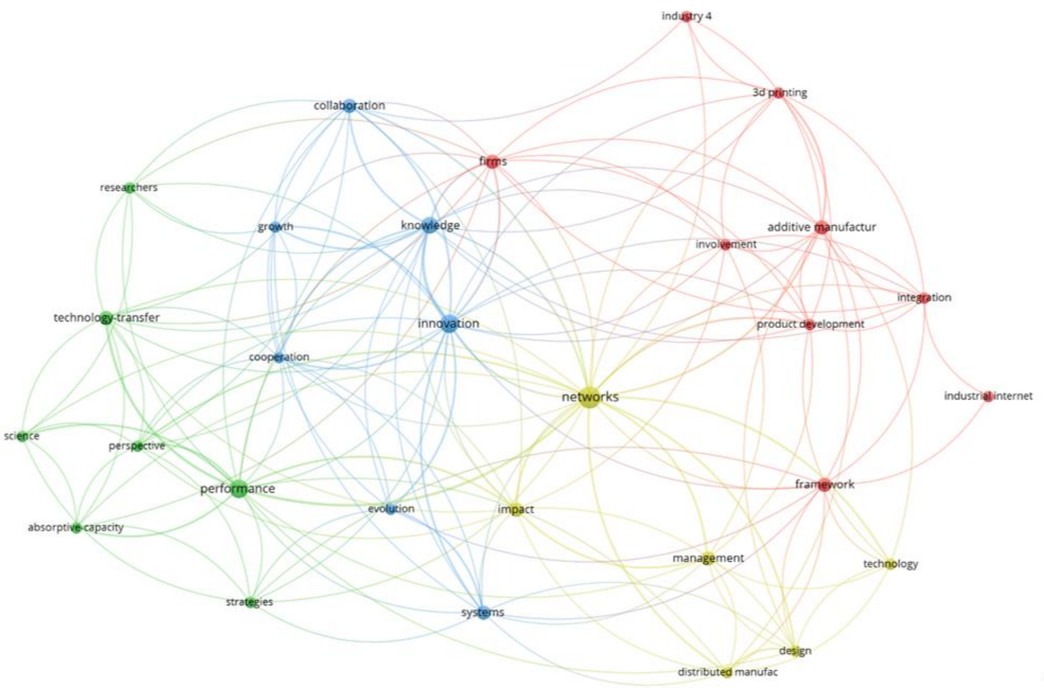

Fig. 1. Co-occurring key words in the 19 research articles.[3]

Based on the co-occurrence of keywords, the themes we researched for the purpose of the study are:

3.1. Emerging Technologies / Innovation:

Lupi et al. and Li et al. investigates blockchain-based shared additive manufacturing, presenting a new network paradigm that ensures transparency, security, and efficiency in

[3] Realized using VOSviewer, www.vosviewer.com

collaborative manufacturing and federated learning to mitigate DDoS in Industrial IoT. These articles point towards the role of emerging technologies in securing and optimizing manufacturing and IoT systems [6], [16].

Rocha et al. and Lupi et al. discuss partnering for digital transformation, including case studies from Brazil occurring in the context of Industry 4.0 and blockchain-based shared additive manufacturing. These contributions reflect on the transformative potential of digital technologies and collaborative approaches in industry practices [14], [16].

Salehi et al. and Moradlou et al. explore commercialization networks and buyer-supplier collaboration in the context of emerging technologies. They emphasize the significance of networks in facilitating the commercialization of new technologies, with a specific focus on nanotechnology SMEs in the UK context [8], [23].

Prabhakaran et al., Kumar et al., and Nudurupati et al. examine the effectiveness of interactive virtual reality in developing distributed manufacturing strategies [18], [21], [22].

3.2. Impact of Collaboration Networks on Performance and Innovation:

Zhao et al. discuss strategies to promote academic engagement, drawing attention to the influence of the university context and individual characteristics within academic networks on engagement levels [15].

Kumar et al.'s analysis on distributed manufacturing strategies from the perspective of a product-process matrix emphasizes the strategic importance of network configurations for achieving manufacturing efficiency and flexibility [21], while Moradlou et al. study buyer-supplier collaboration in emerging technology development, indicating how such networks are critical for managing risks and fostering innovation [23].

Similarly, Guo et al.'s exploration of smart manufacturing networks emphasizes the critical self-organization and self-adaptation mechanisms that allow for enhanced efficiency and dynamic adaptability [7].

Prabhakaran et al., Li et al., and Nudurupati et al. highlight how collaborative technologies and practices can significantly affect organizational performance and innovation capability [18], [19], [22].

Stojcic and Santoro et al. provide evidence of collaborative innovation in new innovation ecosystems in Central and Eastern Europe and the impact of collaborative models with Cultural and Creative Industries on innovation outcomes pointing out how these networks are vital for innovation in emerging systems by bridging gaps between diverse stakeholders. These studies underscore the value of heterogeneous knowledge sources and absorptive capacity in enhancing innovation performance [9], [10].

Fritsch and Kudic delve into the micro dynamics and macro stability in inventor networks, providing insights into how individual relationships contribute to broader innovation ecosystems' stability and productivity [5]. The research highlights inventor networks as examples of complex adaptive systems, despite considerable micro-level changes. An interesting insight from the study suggests that the structural stability of inventor networks can coexist with high levels of individual and tie fluidity due to mechanisms that operate at an intermediary level, such as the transfer of key player roles within the network.

3.3. Framework Programmes:

Oraee et al. focuses on collaboration within construction networks utilizing Building Information Modeling (BIM) technology, identifying influential factors, and proposing a qualitative model for effective collaboration [13]. The article offers a model highlighting how BIM technology facilitates or hinders collaboration in construction projects, addressing technical, organizational, and interpersonal aspects of collaboration, and emphasizes the Innovation Radar's role in fostering innovation within the EU's research and innovation ecosystem.

Pirzadeh et al. offer a sociotechnical network perspective, highlighting the crucial interplay between social and technical elements in shaping design decisions and interactions [12]. The document also emphasizes the development of the Innovation Radar (IR), a platform that offers insights into the innovation processes within extensive collaborative research and innovation initiatives. It aids in monitoring these projects more effectively and offering tailored support to help in the commercialization of results. Moreover, it helps external actors find collaborative partners or investment opportunities by utilizing the public IR data platform.

Li et al. proposes a complexity assessment framework for cloud-edge collaborative manufacturing systems, addressing the challenges of managing complexity and ensuring efficient operation within these collaborative environments and also highlights the importance of network structure in optimizing collaboration and efficiency [6].

Moradlou et al. propose a framework that emphasizes the importance of early-stage incubation in research universities, followed by collaborative efforts either through traditional buyer-supplier relationships or within catapult centres, to successfully develop and adopt emerging technologies [23].

Santoro et al. extend this discussion into the realms of Cultural and Creative Industries (CCIs), pointing out the significant impact of collaborative modes on innovation performance, particularly when networks are enriched with diverse knowledge sources and an absorptive capacity [10].

This is complemented by Nepelski and Van Roy's focus on the importance of networks in facilitating collaboration and knowledge exchange among innovators within Research and Innovation (R&I) ecosystems, highlighting the evolution of the EU's Framework Programme into a comprehensive support system for innovation, emphasizing the role of the Innovation Radar in identifying, managing, and supporting innovations and innovators within this ecosystem [11].

Löfsten & Klofsten and Gronle et al. provide a comprehensive analysis of the symbiotic relationships between science parks that offer infrastructural, technological, and organizational support, while universities provide academic expertise and access to research and development (R&D) capabilities. The studies highlight the importance of strategic management, alignment of goals, and effective communication in maximizing the benefits of these collaborations [17], [20].

4. Discussion and managerial implications

The research findings provide valuable insights on the importance of collaborative networks, digital technologies, and innovative practices in shaping the future of manufacturing, technology transfer, and organizational performance in driving efficiency, innovation, and transformation in contemporary industries that need to be taken into account at managerial level when establishing CRNs.

The articles demonstrate the varied nature of CRNs, from tightly knit groups focusing on specific challenges [5] to expansive networks seeking to leverage broad expertise across fields [3]. The technological backbone, often highlighted in the discussions on smart manufacturing [7] and digital transformation, plays a crucial role in enabling these networks by facilitating communication, data sharing [20], and collaborative problem-solving [17]. Furthermore, the adoption of emerging technologies such as blockchain for shared manufacturing [16] and federated learning for IoT security [19], points to new avenues for addressing prevalent challenges, improving data interoperability, and safeguarding against threats.

Despite the potential of CRNs, several challenges persist. Communication and coordination issues are prevalent, particularly in geographically dispersed networks. Intellectual property rights and trust emerge as significant concerns, especially in networks involving multiple organizations with varying interests. Moreover, securing funding and aligning the diverse cultural and organizational practices of participants pose additional hurdles.

Yet, CRNs present immense opportunities. They allow access to a wide array of expertise and resources, driving innovation through diverse perspectives and knowledge. The potential for increased research impact and the development of new research avenues also stand out, as collaborations can lead to groundbreaking discoveries and the exploration of uncharted scientific territories.

According to the articles researched, there are various barriers and opportunities to effective collaboration in the context of CRNs that we present in the figure below.

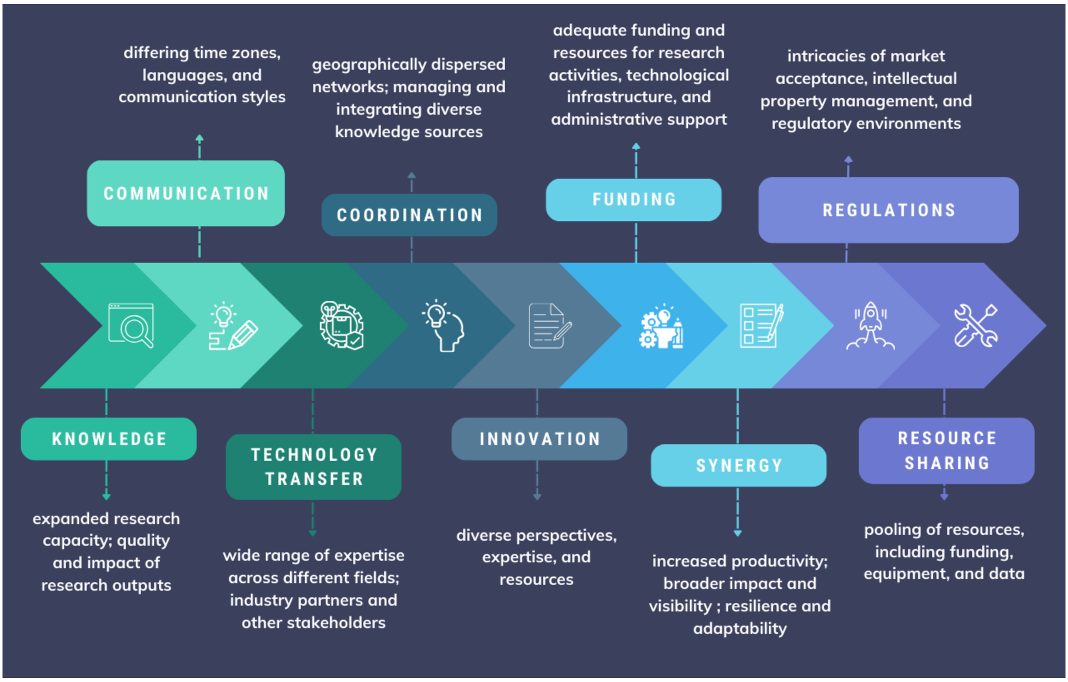

Fig. 2. Barriers and opportunities for CRNs[4]

There are various models or frameworks for CRNs in our research that have demonstrated success, like Cloud-Edge Collaborative Systems, which is a model that successfully addresses efficiency and security concerns in CRNs [6]. By leveraging the strengths of both cloud and edge computing, this model offers a solution to the challenge of processing large volumes of data securely and efficiently, demonstrating the importance of strategic technology integration. Federated Learning for Security Enhancements represents a novel approach to enhancing security in CRNs, especially in the context of Industrial IoT [19]. This model demonstrates the effectiveness of federated learning in addressing cybersecurity threats, a significant barrier for collaborative networks.

Self-Organization and Adaptation in Smart Manufacturing is a framework that allows for flexibility and adaptability, critical for the survival and competitiveness of CRNs in rapidly changing environments [7]. This approach underscores the value of promoting self-organization and adaptive leadership within CRNs.

Blockchain for IP Protection and Resource Coordination is used to overcome barriers related to intellectual property protection and resource coordination [16]. This suggests that secure and transparent technologies are crucial for fostering trust and collaboration in CRNs.

Collaborative Innovation in Emerging Systems show that structured collaboration modes, along with the integration of heterogeneous sources of knowledge and absorptive capacity,

[4] Realized using Canva, www.canva.com

are effective in enhancing innovation performance [8], [9]. This highlights the importance of fostering dynamic interactions and leveraging diverse contributions within CRNs.

5. Conclusions

Our research, besides the synthesis of the state of knowledge regarding collaborative research networks, is proposing recommendations for the development and implementation of CRNs. This contribution not only highlights the foundational importance of collaborative networks in driving industrial advancement but also underscores the potential of CRNs in fostering a more innovative, efficient, and transformative industrial ecosystem.

The synergistic collaboration among various actors in the innovation ecosystem stimulates the development of new products, services, and processes, thus contributing to the enhancement of economic competitiveness [22]. Furthermore, interdisciplinary and intersectoral collaboration paves the way for addressing complex challenges, facilitating the creation of sustainable solutions, and exploiting innovative potential. Therefore, valorization activity, defined as the process of transforming research outcomes into tangible benefits, is closely linked to innovation capacity, and both are enhanced through strategic and effective collaborations in the field of research [8], [9].

A strategy integrating diverse contributions, cutting-edge technologies, equitable benefits, self-organization, flexibility, and stringent security protocols is key to enhancing Collaborative Research Networks (CRNs). Essential to this strategy is the adept incorporation of technologies such as cloud and edge computing, and blockchain, which are instrumental in elevating efficiency, security, and transparency [6], [16].

Promoting self-organization and flexibility [7] allows CRNs to swiftly adapt to new challenges and opportunities, maintaining their relevance and impact. This adaptability is supported by adaptive leadership and governance structures, which enable the network to evolve operationally and managerially.

Key to the success of CRNs is the establishment of clear governance structures, defining roles and decision-making processes to unify participants towards shared objectives. Cultivating a culture of trust and mutual respect is vital for encouraging open sharing and collective problem-solving [12]. Strategic financial and resource management, stakeholder engagement from industry to government, and aligning research with societal needs are all pivotal in amplifying the network's relevance and impact. Mechanisms for ongoing monitoring and improvement ensure the network's adaptability and long-term success [20], while navigating legal and ethical issues upholds its integrity and trustworthiness. These principles are fundamental to developing robust, effective, and impactful CRNs, setting a solid foundation for collective research endeavors.

Expanding on the intention to contribute to the body of work with guidelines and recommendations for the development and implementation of Collaborative Research

Networks (CRNs), the proposed approach involves several key strategies aimed at maximizing the effectiveness and impact of these networks. The recommendations are derived from synthesized research findings, aiming to address common challenges and leverage best practices identified in the literature.

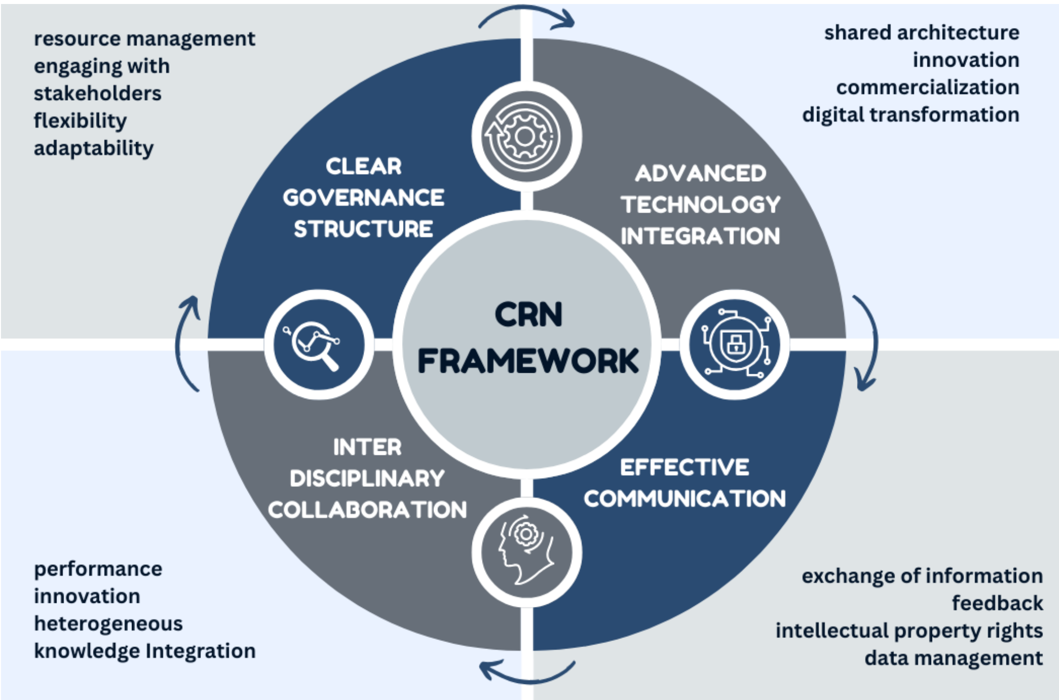

Fig. 3. A framework for CRNs[5]

Considering the scope of this research, a few limitations are identified. Firstly, we must acknowledge limitations in our data collection methods due to the extensive amount of information in the existing literature, and also mention a key limitation related to the highly specific field of study – industrial engineering, which reduces the relevance to broader research or practice. Other manufacturing industries and companies should be explored to obtain generalized results.

Additionally, future research on Collaborative Research Networks (CRN) could delve into several areas to further elaborate on their dynamics, impact, and optimization, focusing on the need for solid frameworks that support the development and functioning of CRNs, particularly in cross-border collaboration.

To corroborate the findings and conclusions of this research, subsequent studies may consider adopting methodologies like surveys and the validation of frameworks.

[5] Realized using Canva, www.canva.com

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