

HOW FAST DEVELOPMENT AND ADOPTION OF DIGITIZED PROCESSES ALLOW MANUFACTURING COMPANIES TO MANAGE COMPLEXITY: BIBLIOMETRIC NETWORK ANALYSIS

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Abstract. High levels of organizational complexity, influenced by interdependence, dynamic linkages, ambiguity, and configurational variation, are increasingly prevalent in the environments in which firms operate. As digital transformation accelerates, these complexity factors intensify, shaping how firms innovate and manage continuously evolving business interactions. This study examines how the fast development of automation solutions enables firms to navigate such dynamic and ambiguous conditions more effectively. A systematic review of 120 peer reviewed publications identifies the complexity attributes most frequently linked to innovation performance. The findings show that interdependence and dynamic linkages dominate discussions on innovation outcomes, particularly in the context of digital and automation enabled transformation. These characteristics, while often perceived as challenges, can also serve as sources of strategic advantage when leveraged deliberately. The study proposes a research agenda that positions organizational complexity across the value creation chain as a resource rather than a barrier. When firms coordinate complex structures and relationships like regulations or sales processes effectively, rapid automation development cycles can help convert complexity into superior innovation capabilities. This perspective highlights the potential for manufacturing companies to not only cope with but also benefit from the dynamic and ambiguous nature of contemporary business environments.

Keywords: business management, process management, literature review, complexity management, digitalization.

Introduction

The changes to the environment in which organizations perform are subject to heavy and rapid disruptions and changes over last years. It is increasingly difficult for organizations to identify causes and effects.

Often the term complexity is used to describe the results of decisions based on vague or unclear information, but there is little to no agreement about a distinct definition of complexity in the context of organization management [1]. While there are many areas like manufacturing [2], programming [3] or product management [4], where research into complexity exists, a distinct and broadly accepted collection of attributes or characteristics that allows to categorize the influence of external factors is missing. Additionally, the growth of factors that influence the day-to-day processes in manufacturing firms grow in number and degree of detail, like very specific environmental reporting [5], quality requirements by customers[6], risk management systems [7] or a rapid growing availability of data produced by the ongoing digital transformation [8]. The introduction of new technologies like ChatGPT in 2021, Robotic Process Automation tools or low-code automation development environments provides stakeholders in manufacturing firms with a growing amount of tools and possibilities [9]. Simultaneously a rapidly changing geopolitical landscape, characterized by the recent pandemic or war does not cut time to allow users a “trial and error” approach [10; 11]. Firms that incorporate adaptive or dynamic capabilities in either their process or their business models [12; 13] still succeed [14; 15].

To accurately describe the state-of-the-art the PRISMA analysis is conducted to identify a qualitative sample of literature over the time frame from 2010 till 2025. A bibliometric analysis of office keywords sources and the connection of those is conducted to identify common alleys of research and clusters. Out of the sample pool the 86 most fitting papers are investigated in depth.

This literature review contributes to the understanding of complexity by further establishing the seven characteristics of complexity and how they are influenced by a rapidly changing business environment. Complexity should not be seen as a hindrance in creating value but rather as a unique factor for the value proposition of organizations.

This study aims to identify successful strategies and actions undertaken by organizations to improve the management of complexity in their individual use case and provide new perspectives on how to improve them.

The structure of the article is as follows: the introduction discusses the relevance of the topic and the theoretical background, next methodology and the conduction of the systematic literature review is summarized, then the results are displayed, conclusions are drawn and limitations are addressed, and finally potential future avenues of research are described.

Materials and methods

The aim of this research is to identify the relevance of innovation in connection with the management of complexity in manufacturing firms and identify possible solutions by utilizing digital technologies or if none are available identify further research recommendations.

To enable comparison of such a wide variety of challenges different theories can be considered. Classical complexity theory, which is based on systems theory as described by [16] allows to differentiate the various factors that describe such a heterogeneous field. Review of seminal papers reveals a set of distinguishing factors that enable differentiation of influences. If the influence of the environmental or structural characteristics of an organization are reviews configurational complexity can be used [17-19]. When describing processes related to the direct value creation in an organization, the characteristic task complexity is identified [20]. The dynamic relationships that change over time are regular attributes [16; 21; 22]. Ambiguity describes the usually unclear degree to which factors influence an organization [17; 23]. Results of changes affecting not singular parameters but have influence on each other can be summarized as interdependence [19; 24]. The term equifinality describes complex interactions that are characterized by the inability to promptly describe which changing factor leads to a changing situation. The trait of asymmetry is used to describe factors whose influence is unique in each interaction or instance. Factors that change over time and the resulting continuous changing interactions can be described as dynamic relationships [16; 21; 24]. To summarize, complexity can be found in the tasks or the structure of an organization, and the interaction of influences on tasks or structure can be described and differentiated with the characteristic's ambiguity, interdependence, equifinality, dynamic relationships or asymmetry.

To take a significant sample of the current state of the art, a PRISMA analysis is created [25]. The filter on SCOPUS was written in a way to identify papers that describe challenges that reflect the complex situation as organizations face since 2010. SCOPUS has been selected as a reputable but single source under the assumption that the literature-sample will not be complete but sufficient for this analysis. Out of 887 initial matches from SCOPUS only 75 remain, as shown with the reasons for exclusion in **Error! Reference source not found.** Furthermore only articles published in PABS 2024 [26] or ABDC 2022 [27] listed journals have been taken into account to assure the quality of the sample.

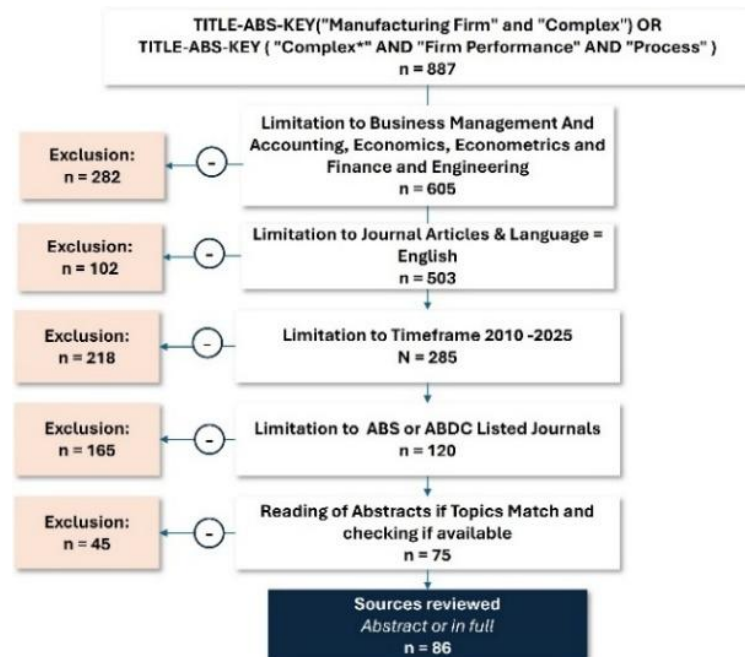


Fig. 1. PRISMA model by the author

Results and discussion

The literature sample of 75 papers originates in 43 different journals and 208 authors contributed to articles featured in this research. Overall, 5823 individual references have been made. The annual scientific production of papers is constantly increasing as shown in Fig. 2. When calculating the life cycle the bibliometrics analysis provides an evaluation of 40%, which puts the topic at the beginning of the growth phase which ranges from 30 to 70% which solidifies the assumption that the topic is relevant [28]. A significant rise in papers can be identified beginning with 2014 with this significant drop during 2022. This drop can be either caused by the corona pandemic which crime is the world's economy to a halt or might be in connection with the public availability of large language models like ChatGPT. As tools for visualizations, either VOS-Viewer or Bibliometrix [29] have been utilized.

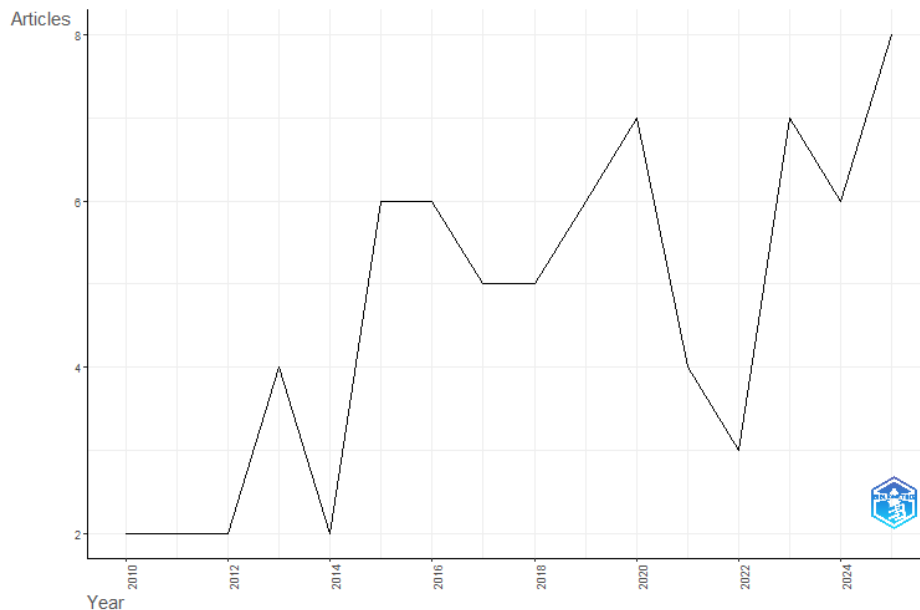


Fig. 2. Annual scientific production

Overall, the sample shows a very heterogenous use of keywords as seen in **Error! Reference source not found.** Since performance is part of the filter, its high relevance is not surprising. While innovation as a keyword is featured only in a third of the journals it still is the second most common keyword. This is due to papers often describing adaptive or innovative behavior without using the term “innovation” as a keyword. While there is a strong connection between innovation and dynamic capabilities, they are not mutually inclusive.

Based on Bradford Law [30] the most relevant sources are Industrial Marketing Management, Journal of Business Research, Business Strategy and the Environment and Strategic Management Journal. The high relevance of a journal that focuses on environmental issues is an indicator that green, environmental and circular topics are a corner point in the complex reality of modern manufacturing organizations.

To better understand the interaction that is the subject of the research described in the papers, the earlier described attributes of complexity are allocated to the papers if they are addressed, either directly or implicitly. The plotting of the co-occurrence of those criteria shows that interdependence is with 57 occurrences the most prominent attribute especially often connected to interdependence and configurational complexity. Overall configurational complexity is featured 40 times, while task complexity only 19 times. Also, asymmetry and equifinality only play a minor role. This indicates that most challenges regarding managing complexity are founded in the structure of a firm and revolve around the challenges induced by rapid evolving environment of the investigated firms.

The investigation of common references supports the earlier assumption that the field of research is highly heterogeneous, with the most commonly cited source, being only cited 16 times [22]. Other commonly used sources that do not address scientific procedures are the seminal work regarding resource based view [31] and the foundation of dynamic capabilities [32] being each referenced 10 times. Since the investigated timeframe of 15 years could also include the rework of a theory, the

theories that are either directly or indirectly referenced in the papers have been marked and plotted out in Fig. 5. This analysis shows that the Resource-Based View theory is the most commonly used scientific theory in the sample. It is commonly used to describe how efficient usage of resources is either a complex problem in itself or how it can be used to describe actions to manage the usage of limited resources. Those actions are commonly described with the help of dynamic capabilities, as the analysis of the most common references already indicated. Agency theory is also a common topic described by the complex interactions of multiple active entities in a system [33]. The relevance of learning is characterized by the high importance of organizational learning theory and how organizations systematically acquire, process, store, and apply knowledge through individual and collective experiences to improve performance, adapt to environmental changes which ultimately leads to gaining a competitive advantage over time [34]. Another frequent approach is the Contingency Theory, which states that leadership effectiveness depends on the match between a leader’s relatively fixed leadership style (task-oriented or relationship-oriented) and how favourable the situational context eventually is. Eventually this is determined by leader-member relations, task structure, and position power [35].

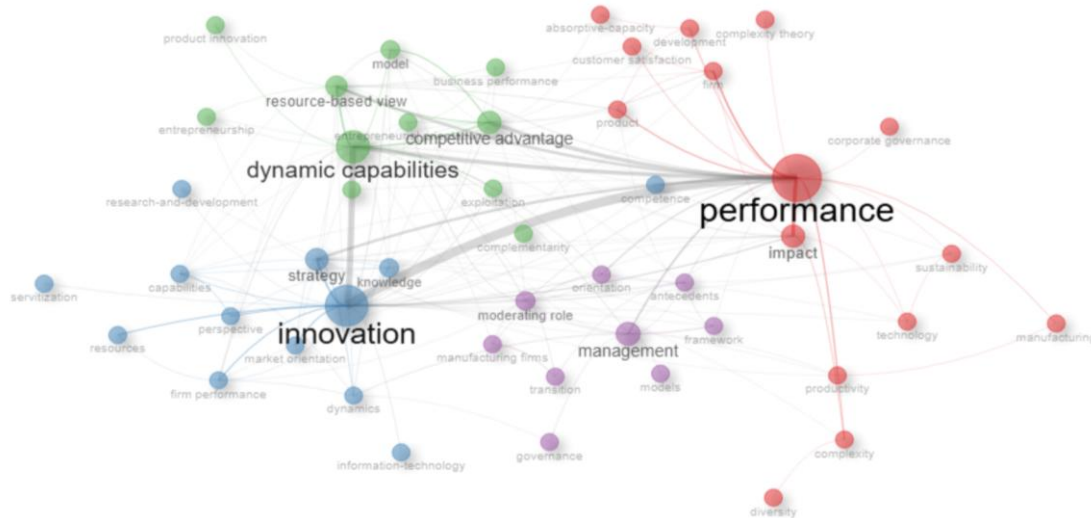


Fig. 3. Map of keywords plotted with Biblioshiny [31]

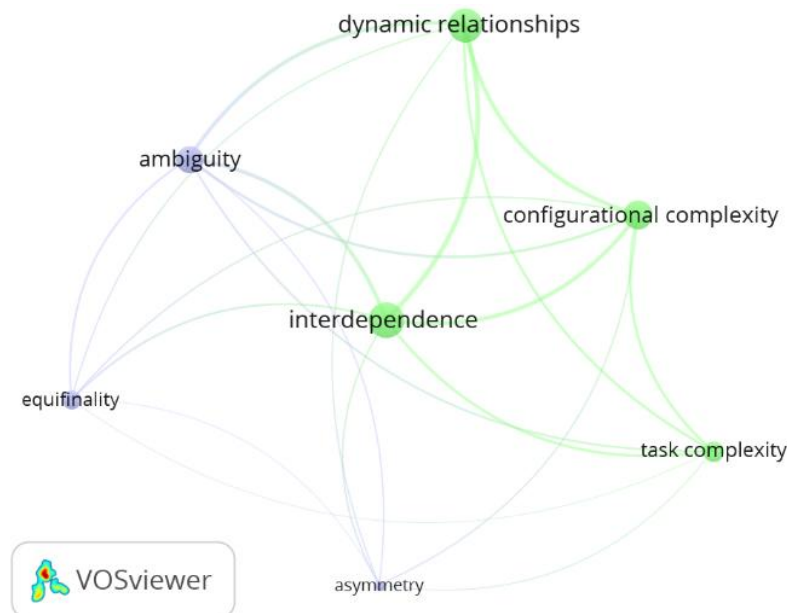


Fig. 4. Co-occurrence of complexity attributes

To better differentiate the individual challenges that rise from the papers in the literature sample, another level of cluster is adapted. 6 non-mutually exhaustive clusters are taken, and each paper can have up to three topicality clusters. The clusters are mutually exclusive, dealing with environmental

regulations can be connected to learning by exporting/internationalization, by addressing different regulations in different countries or the connection between innovation and creation of networks in supply chain or sales [36]. The six different topics used are Adaptation of Scope, Decision Making, Digital Technologies, Environment of the Firm, Knowledge Absorption, and Servitization.

The characteristics are shown in Table 1. The largest cluster is Decision Making with 53 papers being allocated to it, while papers that talk about the utilization of Digital Technologies is the smallest with 22 papers. Papers that discuss the Environment of the Firm, ecological regulations, political stability etc. are on average the newest papers. Servitization is the topic with the highest mean-value of citations ($\varnothing Ci$) which could indicate it as an essential focus area, though this might be influenced by it being also a topical cluster within the highest mean age cluster.

As shown in Fig. 6. the current research focuses significantly more on configurational complexity than on task complexity. Similarly, as shown in Fig. 7 the distribution of the other 5 complexity criteria. Interdependence, equifinality and dynamic relationships are the most researched topics throughout all papers. The count of investigations of managing equifinality or asymmetry is significantly lower than the other attributes.

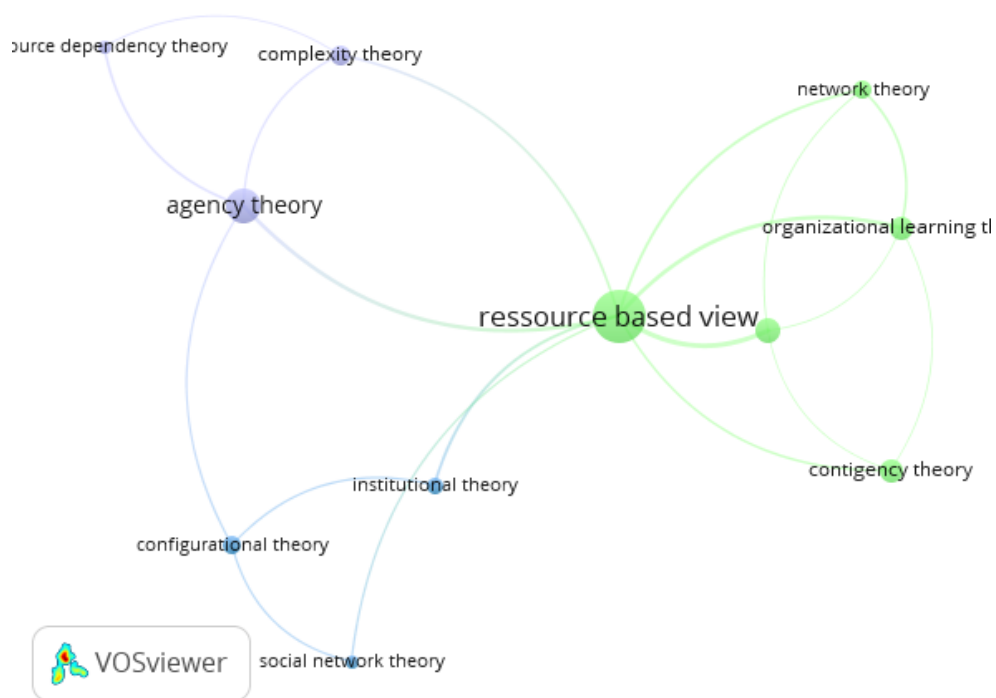


Fig. 5. Co-occurrence of theories

Table 1

Characteristics of the individual topicality cluster

Topical Cluster	$\varnothing Age$	$\varnothing Ci$	#
Active Scope	8	64.7	37
Servitization	8	74.0	21
Digital Technologies	7	52.3	22
Knowledge Absorption	7	53.1	43
Environment of the Firm	6	36.7	34
Decision Making	7	42.4	53

When manufacturing firms grow and expand their scope by exporting or increasing their product portfolio, their organizational structure needs to be adapted. Love and Ganotakis, Corcoles et al., and Freixanet and Federo discuss that firms that successfully internationalize show improved financial performance and adaptability in their core value creation processes [37-39].

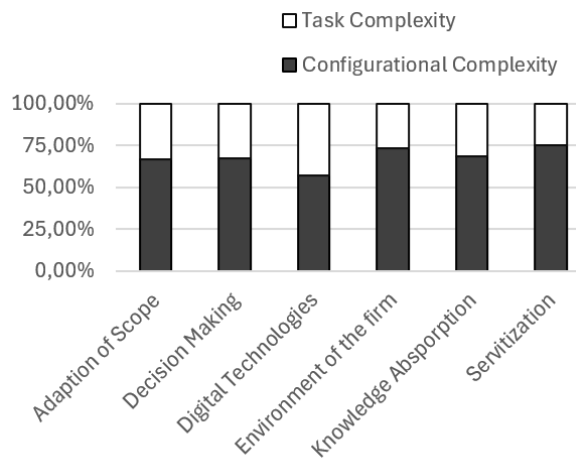


Fig. 6. Distribution task vs. configurational complexity per topicality cluster

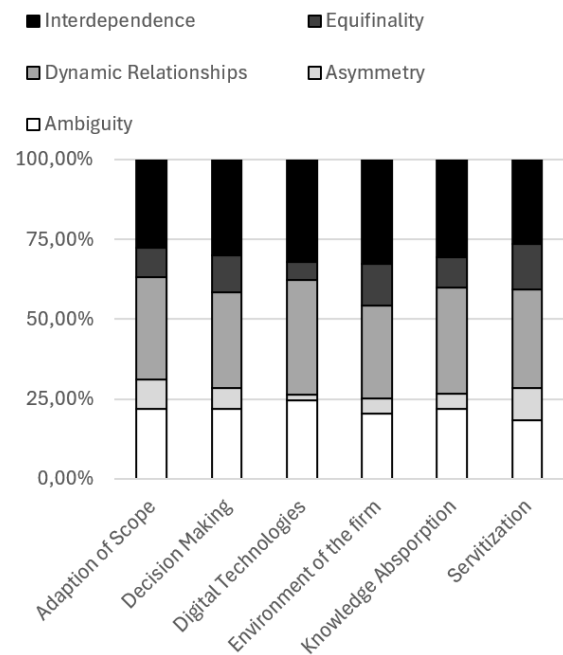


Fig. 7. Distribution complexity criteria per topicality cluster

Parida et al describe how a strong communication and connection of research and development departments while offshoring those functions is a key capability of successful firms [40]. Larsen discusses increasing digitization and commoditization of business processes as a facilitator, especially when offshoring and thereby increasing the structural complexity of a firm [41]. Auzair underlines the importance of establishing distinct management control systems to achieve high performance [42]. The authors agree that the ability to make informed decisions when faced with ambiguity and asymmetry is a key characteristic for well performing firms. Nagy et al investigate the effect of “Configurational Thinking”. This induces a departure from linear, symmetric theory to a more holistic and distinct, configural, asymmetric theory construction in the context of firm strategy [36]. An example of utilization of technology to solve challenges regarding making decisions in the face of ambiguity is presented by Harrison et al, who discuss the application of using supervised machine learning as a solution to manage the overwhelming flow of information towards decision makers in the board of a firm and draw a positive outlook [43]. Kudyba propose a model to better understand the integration of worker/team attributes with collaboration modes, information resources, and augmented technologies to yield effective collective intelligence for decision-making [44]. Chen et al describe the disruption in internal processes that is caused by flu-epidemics and how organizations that deal with more frequent disruptions change their forecasting behavior [45]. This problem can serve as a potential use case for the application of digitalization of reporting processes. Obloj and Sengul discuss that increased reliance on information and communication technologies can exacerbate problems when multiple objectives are followed, despite a positive main effect on meeting performance goals, though the centralization of decision-making structures can improve the overall performance [46]. Such decisions are often influenced by changes in the environment of firms, being new regulations concerning ecological standards or changing markets. Berquist describes with the use case of the Swedish waste and recycling industry the successful adaption of a local industry to new external factors [47]. This was achieved by correctly assessing the change and creating services and adapting the business models. Antonioli and Mazzanti discuss how the inclusion of other partners, in this case trade unions, can be crucial for managing complexity and thereby improve the performance of manufacturing firms [48]. Ajay and Ingole propose firms to “strategically manage leverage and cash holdings” during periods of heightened economic policy uncertainty and emphasize a balance of short term risk aversion and long term value creation [49]. Albeit for service providers, F. Wang et al propose finding this balance by utilizing a data-driven business model that encompasses big data, business model innovation and focusing on data value [8]. The observation can be made that only 25 papers (29%) discuss dedicated technologies or specific applications of such. Since

2015 every year features on average 2 papers that discuss specific technologies. This inherent value creation out of the company data is further discussed in the cluster servitization. Gebauer et al. describe that manufacturing firms that offer additional services to their product portfolio see improved financial performance [50; 51]. They discuss that this task can also be done by leveraging existing networks. In this case innovation is required to identify and utilize the correct resources to improve an existing business model but also technologies could be applied that enable additional improvement for companies. Building upon the idea that cooperation is a necessary skill, Jiang proposes 3 aspects of leveraging existing networks: resource transfer and renewal, reducing uncertainty and ambiguity and strategic resource combination [52]. Hani implies that understanding the dynamics and structural properties of global network competition it is fundamental to manage the complexity of simultaneous cooperation and competition [53]. Eloranta proposes using platforms that connect actors in service driven manufacturing. Such platforms can be created with multiple options [54]. Focusing on marketplaces to create new leads or customers, focusing on order management to improve the service level for customers or utilizing open-source platforms to internalize knowledge provided by other competitors. Ambroise et al discuss that manufacturing firms need to expand their portfolio by services, but need to take care that the internal culture in regards to service is important and key [55].

Conclusions

1. Differentiation of attributes of complexity into task and structural complexity shows that current research focuses on structural complexity, supporting the initial assumption that companies focus more on complexity as a hurdle than complexity as a chance to differentiate the product portfolio. This indicates underrepresentation of research that focuses on utilizing highly complex tasks to improve the business proposition of manufacturing firms.
2. The problems addressed in the literature sample show that factors that pressure manufacturing firms to adapt to a changing environment by innovating their products or behaviors lead to improved financial performance of the firms. Common trends are servitization, adapting to environmental regulations if they are enforced and digitalization.
3. Digitalization technologies are discussed in roughly a third of the literature sample. Those technologies are perceived as a driver of complexity as well as a tool to managing it. Especially in the context of control processes like process and data mining, remote monitoring of equipment or when distributing information, e.g. in the context of remote work the usage of digitalization is described as beneficial for the performance of a firm.
4. In this sample only few papers highlight the complexity induced by the increased amount of information available for decision makers. Since the refinement of information needs to be adapted rapidly if an environment changes, e.g. by a new political crisis, new methods are required to easily automate the preparation of data.
5. The overwhelming majority of papers in this review are based on the perception of complexity by leadership personnel. The view of employees who are increasingly faced with rapid changes in their everyday processes is underrepresented and should be expanded.
6. The increased availability for agentic AI models on the open market and rapidly maturing low-code RPA Platforms like the Microsoft-PowerPlatform open new approaches to managing all dimensions of complexity in a manufacturing firm and could be the focus of more operational focused research.

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Author contributions

Conceptualization and methodology, F.Z., I.M.; analysis and investigation, F.Z.; writing – original draft preparation, F.Z.; writing – review and editing, I.M.; supervision and project administration, I.M.; The data acquisition and analysis, F.Z.; Obtaining funding support, F.Z. All authors have read and agreed to the published version of the manuscript

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