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Design Model Of An Ecosystem For Resilient And Sustainable Value Creation Of SMEs In Single And Small Batch Production

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Abstract

Today's markets are increasingly dynamic, not only due to shorter product development times and fast changing customer requirements but also unforeseen events. Contemporary crises and wars disrupt entire supply chains and can have existential consequences for manufacturing companies. In these times of uncertainty, it is essential for SMEs to have a resilient business orientation while at the same time fulfil the sustainability aspects demanded by their stakeholders. This paper provides a design model for an ecosystem for a resilient and sustainable value creation of SMEs in single and small batch production to increase competitiveness and to gain a better response to market dynamics. The developed model comprises the elements of ecosystem strategy, configuration and coordination. An adequate partner matching and the underlying business model complement the approach. The model is intended to assist practitioners as a reference framework in developing and managing ecosystems for value creation.

Keywords

Ecosystem; Resilience; Sustainability; SME; Single and small batch production

1. Introduction

Companies in single and small batch production manufacture customer-specific and highly complex products such as machines, engineering components or tools for series production. This is done in close consultation with the customer. In order to meet this very demanding environment, a high degree of specialization of the individual producers is necessary, which is expressed in mostly small and medium-sized enterprises (SMEs) in the mechanical and plant engineering sector focusing on certain technologies. Each company has to compete in the market individually, which leaves it at a disadvantage in the event of major market changes or when handling larger orders due to its low resilience and flexibility. Moreover, SMEs in single and small batch production are far from shaping their value creation sustainably. This is often expressed by poor resource efficiency and a constant trend towards overproduction. In particular, this results from a lack of transparency for sustainable value chains [1]. In contrast to series production, processes in single and small batch production are individual, non-linked manufacturing processes. [1] External contract manufacturers in low-wage countries typically carry out a significant share of the value added. This happens even though the company's own machines are only utilized to 34% on average [2]. Currently, the supplier process for contract manufacturers is controlled manually and very statically. Optimization is required in terms of time, cost and quality. In particular, local sourcing strategies should be given greater consideration in the future to increase sustainability and resilience. Therefore, to overcome these challenges, this paper focuses on the development of a design model of an ecosystem for resilient and sustainable value creation of SMEs in single and small batch production.

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2. Fundamentals

In the following subchapters, fundamentals of overproduction and sustainability, resilience and uncertainty as well as ecosystems and platforms for value creation are described.

2.1 Overproduction & sustainability

In the course of the last century, industry has achieved remarkable things as the industrial revolutions have led to enormous efficiency in production. Everyday products are incredibly inexpensive and everyone can afford them. The manufacturing industry has thus made a major contribution to the prosperity of our society. However, it also has led to an economically sensible overproduction, as existing resources are not being used wisely. For instance, the average utilization of a passenger car is just 4%. [3] Due to the efficient production, large numbers of consumer goods are disposed after a short period of use. This overproduction is partly responsible for the increasing environmental pollution and socio-technological consequences, such as massively increased traffic. Due to the extensive global supply chains in the automotive industry, transport cost accumulate to a share of 12% to 21% of component cost [4]. Greenhouse gas emissions continue to rise steadily (approx. 3 million tons of CO_2 emissions annually), and national savings often only lead to carbon leakage, the outsourcing of greenhouse gas-intensive production steps to other countries [4]. A sustainable economy is therefore indispensable for the future viability of the global economy. To achieve this, the United Nations (UN) regularly refines sustainability goals and obliges manufacturing companies to adopt a more sustainable economic approach. Investors are also increasingly applying ESG factors (Environmental, Social and Governance) in their company valuations [5]. The resulting increase in stakeholder-oriented corporate management has led to a fundamental paradigm shift in industry. German automotive companies, for example, are using sustainability ratings to demand sustainable value creation from their suppliers. Such suppliers are often SMEs in single and small batch production, which struggle to meet these demands.

Sustainability has according to the three-pillar conception an economic, an environmental and a social perspective [6]. All perspectives have to be met in an integrated manner in order to holistically improve sustainability within companies. The central enabler of sustainability is digitization [4]. Production and product data allow lifecycle transparency from engineering through production and product usage to disposal. This includes transparency on transport emissions as well as on resource efficiency. BOOS ET AL. make a proposal to leverage these potentials in single and small batch production. They recommend the four dimensions of resources, process, employee and service portfolio to be addressed for sustainability [7].

2.2 Resilience & uncertainty

The recent SARS-CoV-19 pandemic and the Ukraine war have outlined the importance of resilience in supply chain design. Resilience generally describes the ability to cope with crises and to recover as quickly as possible from their effects. Systematic resilience management can decisively help manufacturing companies to get through crises with only minimal damage and even to emerge stronger from them. [8] Therefore, manufacturing companies have to continuously assess the uncertainty in the markets to configure their value creation in a reliable way. Thus, uncertainty is the lever that determines the necessary degree of resilience [8]. WALKER ET AL. define uncertainty as “any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system” [9]. For model-based decision processes, the distinction between nature, localization and level of uncertainty is particularly relevant. The nature of uncertainty describes its general characteristic, while the localization shows where uncertainty occurs in the decision process. Finally, the level of uncertainty can be determined in the dichotomy between total ignorance and deterministic knowledge. [9] As uncertainty assessment and resilience management are complex tasks that require appropriate resources, the vast majority of SMEs in single and small batch production does not engage in it. This can have existential consequences. The scope of consideration in this paper encompasses the resilience of the ecosystem as a whole. In this context, resilience is defined as the preservation of the functionality of the overall system, which is a function of the companies' individual risks.

2.3 Ecosystems & platforms for value creation

In literature, there are still widely divergent definitions of the term ecosystem. MERTENS AND FAISST describe an ecosystem as a network of companies, which rapidly group together in order to take advantage of an arising market opportunity [10]. Ecosystems are traditionally subject to the field of biology. There, an ecosystem intends to maintain an equilibrium state and describes a complex construct of living resources as well as habitats and inhabitants in a certain area including their interrelations [11]. Ecosystems in industry differ in their target orientation and that they require certain governance [12]. However, the idea of a biologically inspired ecosystem implies resilience and the prevention of overproduction in the sense of an equilibrium sustaining state. Ecosystems describe a network of organizations that are interconnected by a digital platform or a focal firm [13]. Moreover, there are various types of ecosystems, which cannot be clearly distinguished from each other, such as business, innovation, knowledge or platform ecosystems [14]. GRANSTRAND AND HOLGERSSON conducted a broad literature review on ecosystem definitions and identified actors, activities, artifacts and relations as central elements [15]. According to a study of DELOITTE, most SMEs have concerns regarding the disclosure of trade secrets, a lack of data security and unclear liability rules when participating in ecosystems. The highest prospects are seen in improved customer relations through better services as well as a sustainable optimization of business processes. [16] The majority of successful ecosystems are based on digital platforms. Digital platforms take advantage of modern information and communications technology (ICT) to reduce transaction cost and to simplify processes for users. Another advantage can be seen in the high scalability of platforms. [17] SMEs in single and small batch production must use these advantages of digital platforms in order to establish successful ecosystems.

3. Existing approaches

The integrative and systematic approach by ULRICH serves as bases to derive general requirements for the design of an ecosystem model for value creation of SMEs [18]. The approach focuses on social and technical systems in terms of design and management. In this respect, the interdisciplinary approach emphasizes in particular the practical applicability of theoretical concepts to solve real problems. By applying the approach, the problems in practice of SMEs of single and small batch production as well as their industry specific characteristics are taken into consideration. Therefore, the general requirements of applicability, practicability and adaptability have to be considered when designing a model of an ecosystem for value creation of SMEs. [18] First, the design model has to be applicable to the industry specific needs of SMEs in single and small batch production. This includes for instance the suitability to the prevailing (production) processes and certain boundary conditions within these companies. Furthermore, the practicability of the design model has to be ensured. Typically, SMEs have few human and financial resources at their disposal. Therefore, the model should be self-evident and easy to apply in industrial practice. Eventually, the model should be adaptable to external and internal circumstances. This encompasses the model's scalability and modification in terms of number and classification of ecosystem participants. Besides these general requirements, also the ecosystem-specific requirements of resilience, sustainability, systemic partner selection, ecosystem composition and control as well as functioning business model must be fulfilled. In terms of resilience, the ecosystem must adapt in line with the existing uncertainty in markets in order to be either efficient or resilient according to the given circumstances. To address sustainability, the ecosystem should foster a sustainable production due to appropriate measures such as interorganizational capacity leveling. On the one hand, this increases the capacity utilization of individual companies within the ecosystem and on the other hand, it prevents overproduction. Thus, all three pillars of sustainability – economic, environmental and social – have to be considered. A systematic partner selection based on resources, competencies and additional criteria constitutes another relevant requirement. In order to achieve maximum efficiency and thus sustainability in the order fulfilment within the ecosystem, orders have to be assigned to companies having adequate resources and competencies at their disposal. Ensuring an appropriate composition and control of the ecosystem represents another requirement. Adequate companies in suitable numbers have to be selected and integrated within the ecosystem. Moreover, a smooth control of the ecosystem and its inherent orders to be processed has to be ensured. Finally, the ecosystem must provide a functioning business model to achieve practical feasibility and broad acceptance. In addition to defining a suitable value proposition for all ecosystem stakeholders and implementing it through appropriate platform functions, the revenue model must also be given sufficient consideration [19].

Subsequently, relevant approaches from literature on ecosystems and value creation networks are presented. Some of these are biologically inspired. TALMAR ET AL. developed their so-called Ecosystem Pie Model, which is a strategy tool for ecosystem modelling and analysis. The process-oriented tool serves to consider ecosystem properties such as interdependencies, complementarities and alignment risks. One of the main challenges is that this approach does not represent a holistic strategy, but merely an operational tool for ecosystem analysis. [20] HENSEL formulates an approach to network management in the automotive industry. The model pursues the overarching objective of analyzing the effects of network management in order to achieve competitive advantages. However, the approach focuses exclusively on short-term project collaborations and therefore long-term collaborations are not discussed. [21] RITSCH developed a concept focusing on knowledge management in networks. Main subject is an adequate partner selection in the dimensions strategy, culture, cooperation and knowledge management experience. The design of knowledge-based value networks follows a methodology with the steps analysis, design and development. The approach lacks an aggregation of the findings in a superordinate model. [22] TANG ET AL. presents different models and methods based on immune-inspired approaches in the field of manufacturing systems. The collection covers various bio-inspired tools for applications to build production plans and deal with unexpected disruptions at the manufacturing level in an agile manner. Although the approaches are partially transferable into fields of action, there is no explicit consideration of holistic value creation networks. [23] DRESSLER ET AL. provide an overview of the general field of bio-inspired networking, including key concepts and methods. The handling of large networks, their dynamical character, resource constraints and robustness is considered. However, the approach provides almost no context for industrial application. [24] SCHOLZ-REITER ET AL. present a simulation model for system dynamics of production networks with real-world data. The model is used to analyze the behavior and performance of bio-inspired capacity control for production networks with autonomous work systems. The model provides a focused view of scheduling, but the simulation model is not transferable and the adaptation requires further testing. [25]

While the presented approaches fulfill some of the requirements, none of the approaches fully matches the general and specific requirements of an ecosystem for resilient and sustainable value creation of SME in single and small batch production.

4. Design model of an ecosystem for resilient and sustainable value creation

Based on the illustrated deficits from practice and theory, a design model of an ecosystem for resilient and sustainable value creation for SMEs in single and small batch production is developed. The model has to take the before mentioned general and ecosystem-specific requirements into account.

4.1 Derivation of the model

The generic reference framework for network design by FRIEDLI ET AL. serves as theoretical basis of the model to be developed. The scientifically proven framework follows the system approach and is derived from theory on global production networks. As intraorganizational production networks exist for a long time and thus have been extensively researched, the framework is perfectly suitable to the context of ecosystems for value creation. The framework was developed and validated with industrial companies, emphasizing its practical applicability. It analyzes production networks from a holistic point of view by addressing the three layers of strategy, configuration and coordination. Adequately and consistently managing these three design layers through decision variables in different dimensions results in a superior network performance. In this respect, it is essential to provide a consistent fit between all three layers but also between the dimensions within each individual layer. [26] Comparing ecosystems with production networks, the major difference lies in the interorganizational characteristics of ecosystems, which have to be considered additionally in the development of the design model. To develop an ecosystem consisting of several legally independent SMEs, these companies must perceive a distinctive advantage in joining the alliance. Therefore, BLEICHER states that respective networks require the conceptual design of an underlying business model [27]. Moreover, in accordance with GRANSTRAND AND HOLGERSSON, the three most mentioned entities in innovation ecosystem definitions – actors, activities and artifacts – are also considered and integrated within the design model [15]. The resulting model of an ecosystem for resilient and sustainable value creation of SMEs in single and small batch production is illustrated in Figure 1. The different layers of the developed model are described in more detail in the following subsections.

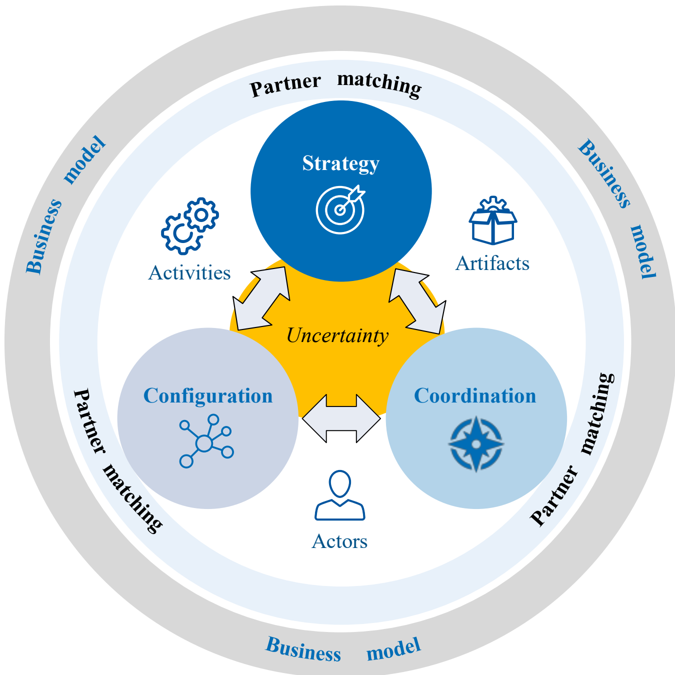

Figure 1: Design model of an ecosystem for resilient and sustainable value creation

4.2 Strategy

Strategy constitutes the first layer within the design model. The layer aims on defining the ecosystem strategy for all participating companies as a whole. The ecosystem strategy represents the business strategy and is composed of the strategic success factors cost, time and quality, which are crucial for the ecosystem's success. Other common differentiating factors for value creation in ecosystems are flexibility and service. These differentiating factors should be based on the competencies of the individual companies as well as of the entire ecosystem. Additionally, the resilience strategy and the sustainability strategy have to be determined. Input to the strategy layer are market requirements and customer needs as well as environmental impacts. All ecosystem stakeholders influence the extent of the sustainability strategy. This includes not only the customers but also the employees of the participating companies. A holistic sustainability strategy covers efficiency, consistency and sufficiency in an integrated manner of the economic, ecological and social dimensions [28]. Efficiency aims at resource efficiency in order to achieve the same results with fewer resources. A lower energy consumption in manufacturing can therefore be seen as an example of an increased eco-efficiency, while socio-efficiency can be seen in fewer negative social impacts per unit produced. [7] Consistency requires a change in the production method, e.g. by recyclable materials or renewable energy. Sufficiency however, aims on minimizing production and consumption in general and thus prevents overproduction. The determinant of the resilience strategy is uncertainty, which is central to the ecosystem model. Environmental impacts, such as the recent SARS-CoV-19 pandemic or the Ukraine war led to large-scale production shutdowns, as many manufacturing companies were not able to adapt and sustain their supply chains in a resilient way. Each of these impacts resulted in a substantial increase in uncertainty. The higher the uncertainty the more resilient the ecosystem should be aligned. To monitor and assess the prevailing uncertainty, sources like the World Uncertainty Index (WUI), providing information on global and country-specific uncertainty, can be utilized [29]. Based on all these preliminary strategic considerations, an adequate value creation strategy for the ecosystem can be derived using the morphological box including dimensions and decision variables in Figure 2. Subsequently, the layers of configuration and coordination can be developed.

Dimensions	Decision variables				
Strategy					
Strategic success factors	Cost	Time	Quality	Flexi-bility	Service
Resilience strategy	Efficiency	Resilience			
Sustainability strategy	Efficiency	Consistency	Sufficiency		
Coordination					
Guidance	Institutionalized	Collective	Hybrid		
Degree of autonomy	Centralized	Decentralized	Neither		
Coopetition	Cooperation	Competition	Neither		
Information flow	Continuous	Discontinuous	Ad hoc		
Resource exchange	Assets	Employees	Neither		
Form of marketing	Centralized	Decentralized	Neither		

Dimensions	Decision variables				
Configuration					
Number of organizations (o)	< 10	10 to 30	30 to 60	60 to 100	> 100
Ø number of employees per o	< 30	30 to 50	50 to 100	100 to 250	
Direction of collaboration	Horizontal	Vertical	Diagonal		
Fields of collaboration	R&D	Design	Service	SCM	HR
Spatial distance	Global	Inter-national	National	Regional	Local
Form of procurement	Global	Centralized	Local		
Form of distribution	Direct supply	Central warehouse	Wareh. near customers	Customer warehouses	

Actors *Activities* *Artifacts*

Figure 2: Morphological box for ecosystem design regarding value creation for SMEs [26]

4.3 Configuration

The configuration layer encompasses the structural design of the ecosystem and its participating SMEs. In contrast to the element-neutral strategy layer, the ecosystem elements from definition apply to the characterizing dimensions in Figure 2. In terms of actors, the average number of employees per organization as well as the total number of organizations within the ecosystem defines the configuration. 40 to 50 companies per ecosystem are considered to be an appropriate number of participants [30]. Additionally, the direction of collaboration has to be determined. A horizontal network is exclusively composed of SMEs in single and small batch production. By adding the vertical direction, suppliers and customers can be included. Diagonal networks supplement organizations from other value chains, e.g. start-ups. The fields of collaboration represent the activities being conducted within the ecosystem. Apart from production, R&D or service partnerships could be initiated. The dimensions of spatial distance as well as the forms of procurement and distribution represent ecosystem artifacts, which are defining the supply chain and the extent of the ecosystem.

4.4 Coordination

Task of the coordination level is the holistic control and management of all partners and activities within the ecosystem. The dimensions of guidance and degree of autonomy refer to the ecosystem element of actors. The ecosystem can either be designed to contain an entity that serves as central orchestrator and thus streamlines all interactions of the participants or define the guidance as a collective task. A hybrid version of certain orchestrating entities serves as another option. Additionally, network decisions and order placements can be centralized, decentralized or a combination of both. Regarding network activities, the participating companies can position themselves in the dichotomy between competition and cooperation. In certain fields, they might compete and in others, they might cooperate. The ecosystem artifacts in the coordination layer focus on the information flow, resource exchange and the form of marketing. Information and communication can occur continuously or only on demand. For increased flexibility and capacity levelling, assets and human resources can be exchanged. Furthermore, the marketing and branding can be centralized or remain in the participating companies. The decision variables of all dimensions have to be consistent with each other and regarding the other layers.

4.5 Partner matching

The partner matching represents a crucial layer in enabling collaboration between SMEs in single and small batch production. It encompasses the strategy, configuration and cooperation layer as it has to take all their dimensions and decision variables into account. As seen in Figure 3, input to the partner matching is information on the internal company characteristics of the order placing company and all potential partners, which should be stored and updated continuously in a common database. Eventually, the trigger of the matching process can be seen in an incoming customer order. Based on the order characteristics in terms of expected quality, cost, delivery time and product complexity as well as the superordinate value creation strategy, a weighting of the matching criteria is carried out. The matching criteria can be classified into two general categories, the categories of interface compatibility and professional competences. In the former, companies should try to achieve the highest possible scores, while in the latter different specifications might be beneficial depending on the boundary conditions. Interface compatibility is divided into criteria for coordination and collaboration compatibility. Coordination compatibility depends on the potential partners' cultural compatibility, coordination and communication competencies as well as technological barriers. Collaboration criteria evaluate potential partners in terms of strategic fit, trust-building factors and the risks of forming a consortium. Resource and competence compatibility represent the general category of professional competences. In terms of resources, financial resources, machinery and intangible assets within each company are analyzed. In the field of competence compatibility, employee qualification, technological and market-oriented competencies as well as innovation capabilities are of importance. Following the assessment, the results and possible project consortiums can be visualized for decision-making purposes.

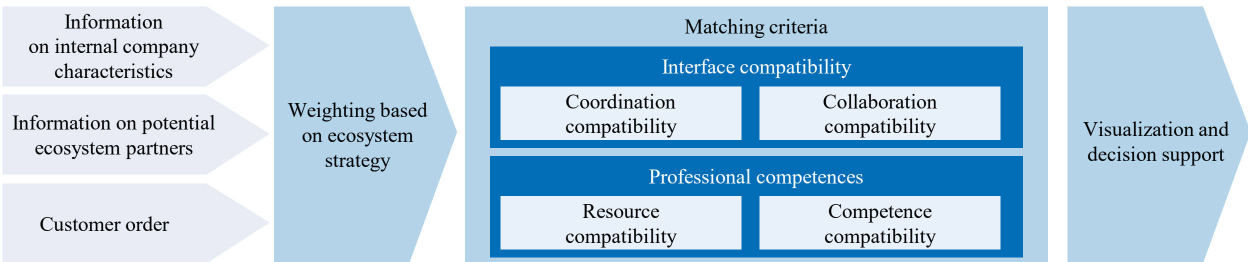

Figure 3: Systematic of partner matching

4.6 Business model

The business model constitutes the outermost layer of the design model, encompassing all other layers. This illustrates the importance of the underlying business model to make an ecosystem for value creation work.

According to STAEHLER, technology-based business models consist of three elements, the value proposition, the architecture of value creation and the revenue model [19]. All three elements have to be considered in depth in order to tailor the ecosystem to the specific characteristics and boundary conditions of SMEs in single and small batch production.

The value proposition reveals the distinctive benefits that the ecosystem provides to its stakeholders. In this respect, it is essential that there exists a sufficient value proposition for each stakeholder or group of stakeholders. Evident groups of stakeholders are SMEs in single and small batch production as well as their customers. However, even within these groups, further distinctions have to be made, e.g. regarding company sizes or industry sectors. Other relevant stakeholders could be orchestrating organizations, which require an appropriate value proposition in order to compensate their coordination efforts. To ensure social sustainability, the ecosystem should be equally beneficial for all kinds of companies.

The primary benefit for the participating companies in single and small batch production is an increase in competitiveness by an optimal use of available manufacturing capacities of a multitude of companies. This includes automated and intelligent order placements and competitive comparisons, partner prioritization, integrated partner management, and capacity alignment to meet on-time delivery commitments. The platform undertakes the time- and resource-consuming search and selection of suitable ecosystem companies for large or highly complex orders through automatic partner matching. Additionally, the ecosystem participants benefit from a free capacity-planning tool, as the majority of SMEs in single and small batch production do not have a planning system. The use of the tool in turn helps the platform with intelligent order placements. Moreover, suitable orders are proposed on the basis of the company's own capacity and technological capabilities. Companies can also achieve economies of scale by intelligently allocating similar orders through the ecosystem to standardize their value creation processes and to increase their margins.

The customers benefit from an automatic supplier assignment based on competencies and specifically selected requirements (e.g. high quality and fast delivery). Customers also gain benefits from a partially automated calculation and the determination of real delivery dates based on real-time capacities. Fast delivery for rush orders is made possible at extra charge by intelligent distribution to several ecosystem companies. The mentioned value propositions and described functions have to be integrated within the platform. Eventually, revenue models can be developed and tested. Suitable concepts could include a transaction-based pricing or membership fees.

5. Summary and outlook

Industrialization has brought prosperity and growth to manufacturing companies. However, it also led to overproduction and a low utilization period of consumer goods. Consequently, more and more stakeholders are demanding for more sustainable value creation in manufacturing companies. In addition, market dynamics recently have been rapidly increasing. These developments pose major challenges, especially for SMEs in single and small batch production. Respective companies are characterized by poor resource efficiency and capacity utilization. Moreover, the individual companies struggle to adapt to changing market requirements or sudden environmental impacts. Resilient and sustainable ecosystems for value creation of SMEs in single and small batch production represent an adequate measure to tackle these challenges. In literature, there exists no suitable approach for ecosystem design, which meets the industry-specific characteristics and boundary conditions. Therefore, this paper presented a design model of an ecosystem for resilient and sustainable value creation of SMEs in single and small batch production. The model is derived from the generic reference framework for network design by FRIEDLI ET AL. and the elements of ecosystem definition by GRANSTRAND AND HOLGERSSON. The developed design model comprises five layers. The strategy layer determines the value creation strategy based on resilience and sustainability objectives. The configuration layer defines the physical structure of the ecosystem, while the coordination layer focuses on ecosystem management and control. The partner matching encompasses the above-mentioned layers and composes optimal project consortiums within the ecosystem. Eventually, the business model defines the value proposition, the architecture of value creation and the revenue model of the platform. The results are more stable, faster and self-configurable value creation systems that ensure rapid and successful adaptation to changing environmental conditions or order volumes. By working together in core business areas, strategic goals can be achieved that are usually outside the capabilities of the individual companies. Future research should focus on the specification of the platform functions as well as the development and testing of reasonable revenue models.

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Biography

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