7th Conference on Production Systems and Logistics

Life Cycle-oriented Information Structuring Concept for Circular Product Strategies

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Abstract

Circular economy in form of cross-life cycle management of products and closing of material flows is the central instrument for manufacturing companies to implement sustainability economically. The focus is on closing loops through various circular product strategies. These strategies extend the usage duration and strive for recycling at the end of the life cycle of products, facilitating the transition from linear to circular economy. The implementation of these strategies is currently associated with major obstacles, which primarily result from the high level of complexity involved in developing and executing these strategies. To derive actions and design measures for the management of products along the entire product life cycle, companies need a sufficient amount of information as a basis for decision-making. The key to this is life cycle product data. Currently, there is no scientific approach to collect data contextually and extracting relevant information for implementing circular product strategies. In manufacturing industry, there is a lack of knowledge about how companies can identify specific information they need from various life cycle phases to implement circular product strategies. This is primarily due to the fact that this information is not located exclusively within the boundaries of the firm, but is increasingly held by various actors within business ecosystems. This research approach aims to conceptualize and outline a methodological approach to enable life cycle-oriented information structuring for the implementation of circular product strategies in business ecosystems.

Keywords

Sustainability; Circular Economy; Information management

1. Introduction

Sustainability and digitalization mark megatrends in innovation management and play a major role in today's business environment [1]. The increasing signs of climate change, growing competition for scarce natural resources and an environmentally conscious society will further increase the pressure on companies to develop new products under consideration of environmental aspects. In addition, national and international legislation requires companies to take responsibility for the entire product life cycle. For example, action plans like the European Green Deal embody legislative pressure. Sustainability must be also perceived as a strategic opportunity to generate competitive advantages. Progressive, sustainable product and process innovations allow companies to differentiate themselves from competition [2]. To shape these innovations, concepts are required that link companies and value creation processes with their ecological environment in a systematic and success-oriented manner [3].

DOI: https://doi.org/10.15488/18912
ISSN: 2701-6277

At the same time, digitalization is changing the macro-environment of manufacturing companies [3, 4]. It is primarily enabled by the increasing networking of people, machines, products and the resulting data. There is discussion regarding the interplay between sustainability and digitalization. Current research has shown that the combination of these two megatrends harbours potential for sustainable corporate success [5].

Circular economy, in the form of closing material flows, is the central instrument for manufacturing companies to operationalize sustainability [6]. Since complex activities must be carried out in different life cycle phases for the circular management of products, extended competencies are required. Value creation in the circular economy no longer takes place exclusively within the traditional boundaries of the firm. Instead, value creation is localized mostly in business ecosystems, which are networks where several companies interact to jointly provide a product or service that each company could not offer on its own [7].

The transition to circular economy is in its early stages. In recent years, some companies have introduced new methods to foster sustainability in the value chain in the form of circular strategies. To derive actions and design measures for the management of products in the circular economy, companies need a sufficient amount of information as a basis for decision-making. The key to this is cross-life cycle product data [8]. In manufacturing industry, there is a lack of knowledge about how companies can identify specific information they need from the various life cycle phases of their product in business ecosystems to implement circular product strategies [9]. This problem is due to the fact that companies are increasingly operating in ecosystems and information is therefore no longer located exclusively within traditional boundaries of the firm but is held by various actors in the ecosystem. [10]. Companies must be enabled to identify relevant information for circular product strategies in ecosystems and to record it in a structured way. Taking into account concrete demands for intensified research e.g. [4, 11, 12] the goal of this approach is to present a conception of a methodology for information structuring and localization across product life cycle phases in business ecosystems via information models for the implementation of a circular product strategy. This conceptualization will be detailed in following research approaches. For this purpose, following explanation of relevant fundamentals, approaches are evaluated regarding their suitability for solving the problem and a research gap in existing literature is identified. This is followed by a description of the methodology proposed. Finally, the results are summarized and an outlook on further research activities is given. The aim of the research approach is to demonstrate the concept of a methodology which paves the way for following research projects. The paper adheres to the research process with theoretical and practical relevance according to [13]. The process is characterized by the identification of relevant practical problems, the investigation of existing scientific approaches, the derivation of design rules and the transfer of the results into practice.

2. Theoretical Background

The following section highlights the current state of research and preliminary work. Among the most relevant aspects when considering life cycle-oriented information structuring for circular product strategies is a common understanding of circular economy as well as information management in manufacturing industry.

2.1 Circular Economy

According to [14], circular economy can be understood as an industrial system characterized by a restorative and regenerative concept. The central goal of circular economy is to maintain products, components and materials at their highest use or value at all times, so that a minimization of resource use and generated waste is achieved. Thus, this economic model is not only ecologically beneficial, but also offers new economic opportunities by promoting innovation and sustainable business models [3].

A key concept of circular economy is the emergence of the so-called systems perspective [15]. This transformational change goes beyond closing materials, components and products loops and promotes

sustainability in the way resources are exploited, used and managed throughout the system. It focuses on the dynamics between processes, values and actors in the value chain, and their dependence.

Circular strategies are another key element of circular economy. These strategies are usually referred to as "R-strategies" [15]. R-strategies aim at reducing the consumption of natural resources and minimizing negative environmental impacts. They can be considered as a basis for designing measures for slowing down, closing and narrowing material cycles [16].

According to [15], companies must formulate and implement circular business strategies to be successful in the context of circular economy. [17] defines business strategies as strategic initiatives a company pursues to create value for the organisation and its stakeholders and gain competitive advantage in the market. This strategy is crucial for a company's success and is needed before any goods or services are produced or delivered. Taking into account the principles of circular economy, a company has to formulate adequate circular product strategies to create, communicate and extract value based on circular principles. The implementation of strategies must be based on sufficient information [18, 19]. Therefore, the following section considers information systems research in the context of circular economy.

2.2 Information system research

According to [20], information management is classically regarded as an integral part of corporate management. The main objective is to make optimum use of information as a resource with regard to the company's goals. Information system research in manufacturing industry in the context of the circular economy is characterized by life cycle sustainability [8] and aims to support the implementation of circular strategies. Products and components can have different states over several life cycles and usage phases. Both circular economy strategies and suitable technologies are required in order to manage products and components in cycles and thus enable multiple life cycles. In this holistic sustainability perspective on the life cycle of product, physical product life cycles are supplemented by a data sphere. This data sphere enables a sustainability assessment by means of suitable key figures and contains the necessary information that enables actions and the application of sustainability strategies [8]. In the course of establishing a circular economy, a central challenge in the design of information systems results from the system thinking mentioned above. Instead of the classic linear value chains, business ecosystems are increasingly appearing in which actors create value together based on coopetition [9]. As a result, the information that is generated along the life cycle of products, such as maintenance activities, upgrades or other usage information, is distributed across all actors and is therefore fragmented in the ecosystem. The introduction of circular economy in manufacturing industry is an information problem [21].

2.3 Interim conclusion & Research gap

To organize and guide entrepreneurial decisions, an appropriate ontology is required. Various research approaches have already applied principles of information system research to facilitate business strategies [22]. Recent approaches have developed information management concepts for domain-specific applications in context of the circular economy, e.g. for building and construction industry [23], reverse logistics [24] or supply chain management [25]. These approaches are either too general or too specific from the perspective of localization and structuring of information requirements for the implementation of circular product strategies in business ecosystems. In particular, there is no integration of fundamental principles of circular economy in manufacturing industry. Especially the system perspective, which is essential in this context, is not sufficiently taken into account. There is insufficient consideration of the role of business ecosystems and its actors. Existing approaches tend to argue from a single-view and use case perspective. This industry and domain focus makes it difficult to transfer and derive generally applicable principles. A conception of a methodology for life cycle-oriented information structuring for circular product strategies as a starting point for further research activities and detailing is needed.

3. Conception of a methodology for life cycle-oriented information structuring for circular product strategies

The following section describes the conception of the methodology. In order to clarify the application of the conceptualization, a company -centric perspective is adopted. The derivation of this concept of the methodology is based on various literature reviews and interviews with experts regarding the requirements for life cycle-oriented information structuring for the implementation of circular product strategies.

The proposed concept of a methodology for life cycle-oriented information structuring for the implementation of circular product strategies in business ecosystems consists of four steps (see fig. 1). First, a concept of a framework for the description of circular product strategies in manufacturing industry is provided (sub-model A). Second, an approach for the description of business ecosystems in the context of the circular economy in manufacturing industry is characterized (sub-model B). Third, a concept for the determination of company-specific information requirements is provided (sub-model C). Fourth, a procedure for designing a product information model for the implementation of circular product strategies in business ecosystems is outlined (sub-model D).

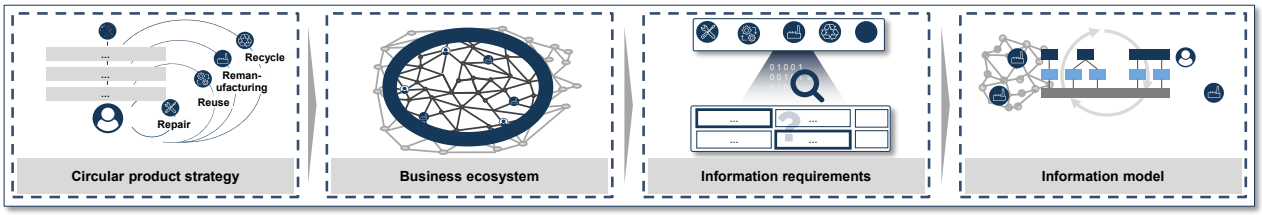

Fig. 1: Structure of the concept for the proposed methodology

3.1 Conception of a description model for circular product strategies

As circular economy grows in popularity, its interpretation and implementation diverge considerably. To provide companies with common language circular product strategies are described using dimensions and associated characteristics. Building on key dimensions like e.g. “focus”, “level” and “technical loop” identified by previous research approaches [e.g. 4, 9, 15] further dimensions and characteristics are outlined. Accordingly, a circular product strategy can be described primarily along the dimensions life cycle phase involved, stakeholder involved, enabling elements and technologies, closing loop management model and circular business model involved. The aim is to provide an elaborated understanding of circular product strategies beyond the traditional focus on R-strategies, in the sense of the circular management of materials, and to integrate the business model perspective. A morphology provides a systematic structuring and description of this circular product strategies. Subsequently, relevant design options are listed for each design dimension, which enable an operationalization. Thus, companies are provided with an instrument for recording the design space of circular product strategies on a standardized definition basis. Figure 2 illustrates this concept by way of example.

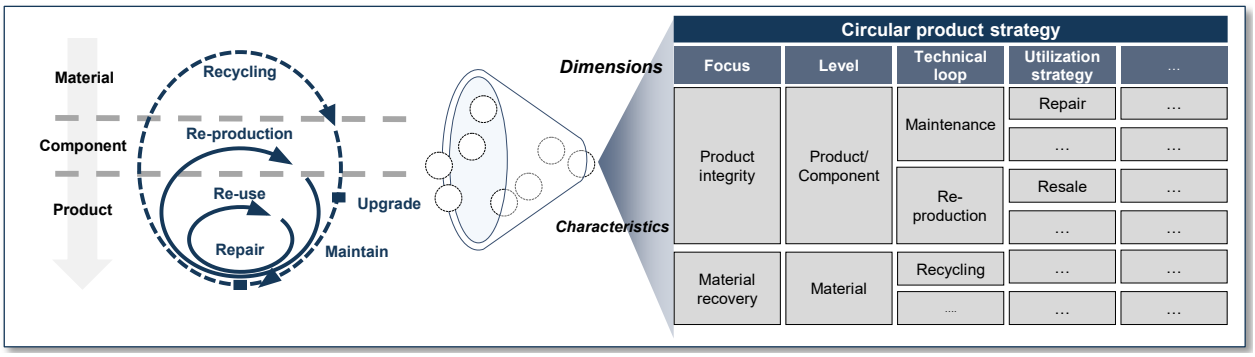

Fig. 2: Conception of a morphology for circular product strategies

Based on this description, a procedure for the individual derivation of strategies for a company is outlined. Companies should be enabled to identify individual constellations in the morphology. First, an approach for describing a target system is provided. Methodologically, this is based on the synthesis of the strategy wheel for business strategies [29] and the approach of the costumer journey [30]. Following the premise that there is no "one-fits-all approach" in the context of selecting circular product strategies [31], a procedural principle is outlined, based on a materiality analysis [32], which enables companies to describe individual circular product strategies. The resulting strategy wheel for circular product strategies serves as an operationalization instrument of the morphology and enables companies to identify individual characteristics of their pursued circular product strategy.

3.2 Conception of a description model for business ecosystems in circular economy

While circular strategies are considered strong enablers for circular economy [33], research often takes a single view and is limited in its ability to show the systemic implementation of circular economy principles that span across firms and actors. An increasing number of scholars agree that collaborative networks, multi-stakeholder collaboration and effective business ecosystems are required [10].

Various roles in business ecosystems were identified based on structured literature research. In order to make these roles accessible for companies for the description of roles in business ecosystems in the context of the circular economy, a formulation of "role maps" [35], as a characterizing element, is provided. Figure 3 illustrates this principle. These role maps enable companies to characterize players in business ecosystems based on the properties of primary task, activities performed and resources used. This description enables companies to characterize to what extent and by what means which actor in the ecosystem contributes to the implementation of a circular product strategies. The value chain is also described in the context of the circular economy using standardized elements to enable companies to create transparency about the life cycle of their product.

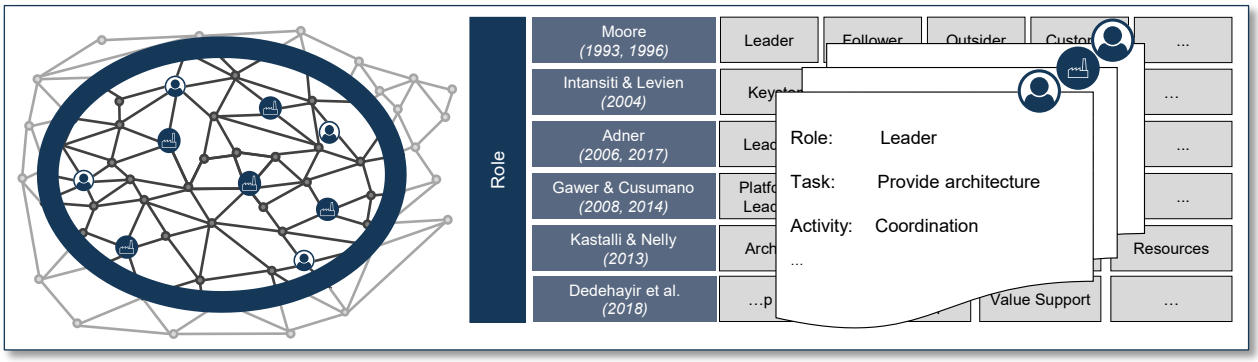

Fig. 3: Conception for the description of business ecosystems and its actors

Based on the description of actors in business ecosystems in the context of circular economy, the following step promotes a procedure for the derivation of an individual description of the business ecosystems depending on a specific circular product strategy (see step A). The methodological approach of a supplier-input-process-output-customer (SIPOC) analysis [36] is employed to derive different value creation steps along the product life cycle. Based on the previously defined role maps, the required actors can now be assigned. As a result of sub-model B, a description approach for business ecosystems in the context of circular economy can be pointed out.

3.3 Conception of an explanatory model for the determination of information requirements

A sufficient information base is essential for successful strategy implementation [9]. As an explanatory model, this sub-model aims to develop a concept of a methodology for identifying information requirements in business ecosystems for the implementation of circular product strategies.

Information requirements are defined as the type, amount and quality of information that a decision maker needs [37]. They vary with different tasks, vary in time, or depend on the decision maker's frame of mind [38]. Thus, the information requirements for circular product strategies need to be determined. A procedure for determining the information requirements profiles of the various circular product strategies is provided, taking into account the principles of business system planning [39]. Afterwards, critical informational success factors [40] for the implementation of circular product strategies are identified. The information requirements are then mapped to the phases of the circular product life cycle to identify the actors who have this information.

According to [41] and [42], constructing a company-specific information model can be supported by the reference modelling approach. Consequently, companies should be offered a tool that facilitates the development of an individual model of a company-specific application case. This model includes especially a principle for structuring the contents using suitable artefacts. To this end, the cross-life cycle information requirements are structured based on the definition and characterization of "information carrier" artefacts, i.e. generic information carrier types in the ecosystem (in the sense of entities), the definition of the "information requirement" artefact, i.e. the definition of generic information requirements (in the sense of attributes) and the definition of "descriptive information" (in the sense of relationships). Based on this approach, a semantic structuring approach for cross-life cycle information requirements in business ecosystems is derived. Figure 4 shows the conceptual structure.

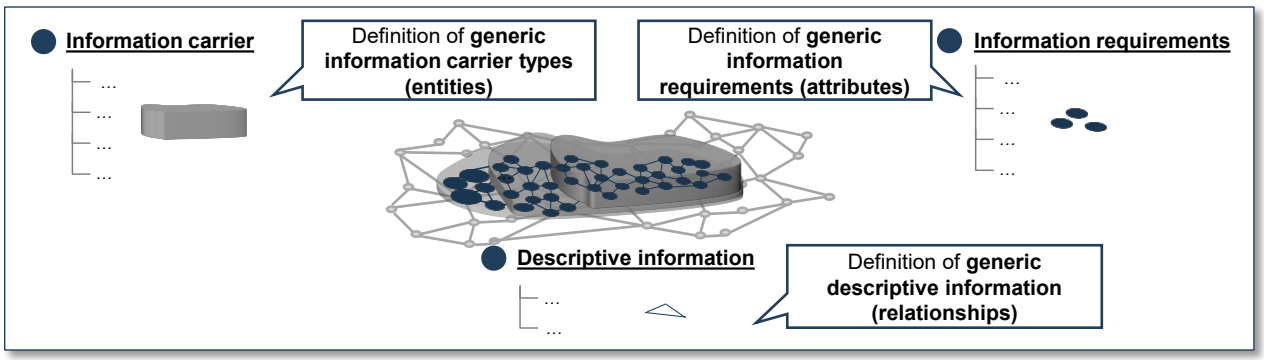

Fig. 4: Principle for structuring the contents of the information model using suitable artefacts

3.4 Conception of a design model for a product information model

Information serves as answers to questions and thus as transferable knowledge [20]. To transfer this knowledge between actors, they must be able to coordinate with each other. Therefore, information needs to be organized into a structure. Consequently, sub-model D focuses on mapping the structured information requirements using suitable information models.

To map the structured information requirements via a product information model, considering their distribution in the business ecosystem, it is necessary to link every information to the corresponding information carrier. With recourse to the results of sub-model 2 and sub-model 3, information carriers can be assigned along the cycle-oriented value chain and information can be localized. Afterwards resulting architecture of circular product systems can be modelled. The modelling approach is carried out with the help of Entity-Relationship Modelling (ERM) principles [43]. Entities are found in the form of the description of actors in the ecosystem (sub-model 2), attributes are found in the form of information requirements (sub-model 3) and relationships in the sense of localization along the value chain from the previous step. The overall result is an information map.

Building on this, a conception of a methodology for constructing the framework for a semantic product information model is provided. The procedure for drawing up an information map described in sub-model 3 must be enhanced to enable operationalization and a company-specific implementation. This methodology takes into consideration the corresponding business ecosystem and the cycle-oriented value chain (sub-model 2) based on a company-specific circular product strategy (sub-model 1). Also, it takes into account the structuring of the necessary cross-life cycle information requirements (sub-model 3) and the localization of them (sub-model 4). A corresponding framework of a product information model is used for mapping this information. This schema serves as the formal structure of the information model [37]. Finally, the modelling is carried out with the help of Unified Modelling Language (UML). The advantage of this modelling technique is that the result can be used as a standardized communication tool in a variety of company processes and promotes the accelerated development of the necessary product information models. Figure 5 illustrates this concept.

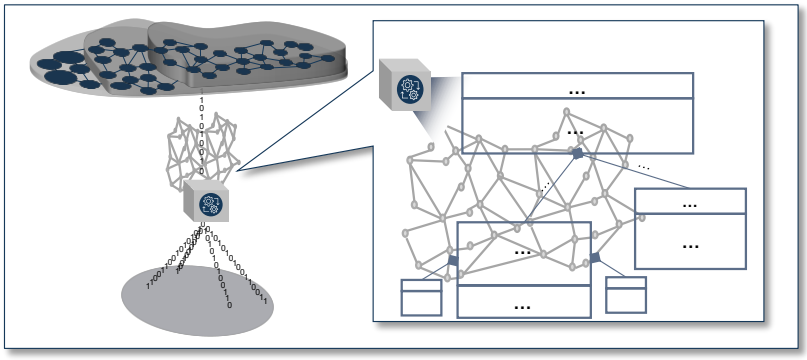

Fig. 5: Concept for the framework of a semantic product information model

The result of sub-model D is a methodology for life cycle-oriented product information structuring for the implementation of circular product strategies in business ecosystems via product information models.

4. Conclusion

Based on this conception of a methodology for life cycle-oriented information structuring a vehicle for the implementation of circular product strategies in business ecosystems is presented. This approach serves as a reference architecture and outline of a methodology that provides help for describing a procedure of company-specific development of circular product strategies, location of information requirements in business ecosystems and structuring via a product information model. It provides consistent definitions of systems, methodical consistency, procedural principles, as well as a common vocabulary to discuss specifications of implementations. In summary, this conception of a methodology represents a meta-theoretical blueprint to systematize the research area, to focus on further research approaches and to provide companies with conceptual guidance.

From the results serval implications for theory and practice can be drawn. Regarding scientific contributions, the research approach addresses that the implementation of the circular economy is primarily an information problem [21]. Within the presented approach, the information problem is traced back to the required systems perspective in connection with circular economy [7]. The approach concretizes this systems perspective by providing a framework for the description of business ecosystems in the context of the circular economy and proposes a procedure for information localization and structuring. Based on this, a framework for the design of a semantic product information model is derived which solves the information problem. This information model systematizes the research area in the sense of an ontology and can serve as a starting point for further research initiatives.

As for managerial contributions, the approach outlines an application-oriented process model that can enable companies to implement individual circular product strategies. The methodology highlights fields of action

for companies and can serve as a blueprint for designing suitable information management concepts. The proposed framework of a semantic information model forms the foundation for promoting interoperability in view to the exchange of information in business ecosystems based on a uniform system design.

The approach is limited by a few aspects that must be considered when interpreting the results. Since the aim of the approach was to develop a concept of a methodology, this conception must be detailed in subsequent research approaches. The solutions outlined must be validated in practice, tested and, if necessary, expanded, for example in the form of conducting multiple cases [44]. This detailing is currently taking place in a research project at the RWTH Aachen Campus.

Consequently, by adopting a systems perspective, the approach presents a consistent conception of a methodology for life cycle-oriented information structuring in business ecosystems for the implementation of circular product strategies and provides a promising basis for conducting further qualitative and quantitative research approaches.

Acknowledgement

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC – 2023 Internet of Production – 390621612.

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Biography

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