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Guiding Principles For The Manufacturing Industry For Establishing Re-Assembly

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Abstract

To reach the aligned climate goals the manufacturing industry needs to face a paradigm shift and decouple resource consumption from economic performance. In this context, the approach of circular economy has the potential to implement sustainability in the industry while being profitable at the same time by preserving the product's value and reducing the material-induced emissions. The corresponding R-strategy Re-Assembly, in short, the industrialized reconditioning of products with upgrades, tackles this issue by enhancing the product's value during the usage phase. However, the concept is not yet sufficiently established in scientific literature and industrial practice as other R-strategies already are. In order to enable its introduction in the manufacturing industry, this paper analyzes the characteristics of Re-Assembly and delimits the term in the literature. By conducting a systematic literature review, related topic areas, such as remanufacturing, continuous innovation and product upgradeability, are identified and checked for overlaps. With a subsequent PESTLE analysis, the characteristics are summarized and visualized. Finally, the results are verified by expert interviews with representatives from the manufacturing industry. This paper facilitates the definition of Re-Assembly, supports the identification of use cases and results in guiding principles for the manufacturing industry to establish Re-Assembly as well as potential fields for further research.

Keywords

Sustainability; Re-Assembly; R-strategy; Circular Economy; Innovation Management

1. Introduction

Driven by current climate protests in the EU, the issue of sustainability is becoming increasingly prominent. The EU's ambitions and the resulting regulations, such as the CSRD (Corporate Sustainability Reporting Directive) [1], let sustainability evolve into a necessity for corporate activity. More and more companies are therefore focussing on the transformation of their value creation and the formulation of sustainability targets [2]. In this context, the approach of circular economy shows great potential, as it offers an opportunity for profitable sustainability [3]. In addition, international business is increasingly being disrupted by geopolitical conflicts [4], which increase the attractiveness of the circular economy and sustainable resource management due to the associated reduction of resource dependencies. The circular economy and its connected R-strategies are capable of decoupling economic success and growth from resource consumption and environmental pollution [5]. This aids companies in reaching set climate goals and decreases their resource dependency from volatile sources at the same time. Especially the R-strategies that focus on the efficient preservation of a product's value and therefore the enhancement of its ecological sustainability are appealing

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for the manufacturing industry. The R-strategy Re-Assembly, in short, the industrialized reconditioning of products with upgrades, enhances this idea further but is not yet sufficiently established in scientific literature and industrial practice. Hence, this paper aims to foster the establishment of the strategy Re-Assembly in the industry by analyzing the attributes of Re-Assembly and delimits the term in the literature. The resulting guiding principles address companies that are considering Re-Assembly and are linked to related topic areas from the literature, thus, serving as a starting point for further research.

In the following chapter, the fundamentals and relevant terms are described and relevant research is summarized. Chapter 3 contains a description of the paper's research approach. Chapter 4 displays and discusses the research findings, which are summarized in Chapter 5.

2. Fundamentals and related research

In this chapter, the basic terms of "circular economy" and "R-strategies" are defined. Subsequently, the term "Re-Assembly" is explained. This is followed by an overview of related work on Re-Assembly.

2.1 Circular Economy and R-strategies

The fundamental goal of circular economy is to decouple economic growth from the consumption of finite resources and to extend product life cycles [6]. It is intended to reduce dependence on raw material suppliers, cut costs in the supply of raw materials and energy, and strengthen environmental protection [7]. For this, the circular economy requires a change in the way products are developed, produced and used. To implement this, there are various strategies, so-called R-strategies, which operationalize the closure of corresponding resource loops in various ways. In literature, there are multiple definitions and granularities regarding the R-strategies. However, the five R-strategies that are most common are reuse, repair, refurbish, remanufacturing, and recycling. [8] These strategies, as originally defined by POTTING ET AL. [9], focus on the closure of resource loops. The extension and deceleration of the loops, e. g. with upgrades, is elaborated separately in literature as described in chapter 2.3 and are not considered in the R-strategies yet. Figure 1 displays how circular economy can address ecological and economic goals. The graphic illustrates that sustainability and circular economy is more than saving energy or recycling. The sustainability transformation needs other aspects, such as life extending measures and value enhancements, to be successful. Upgrades in this context are defined as functional or esthetical product adjustments that enhance the product's value for the customer. Since the industrialized and therefore profitable implementation of upgrades in the usage phase is not yet sufficiently considered in the R-strategies and related processes are currently carried out similar to non-industrial workshop production Re-Assembly complements the R-strategies.

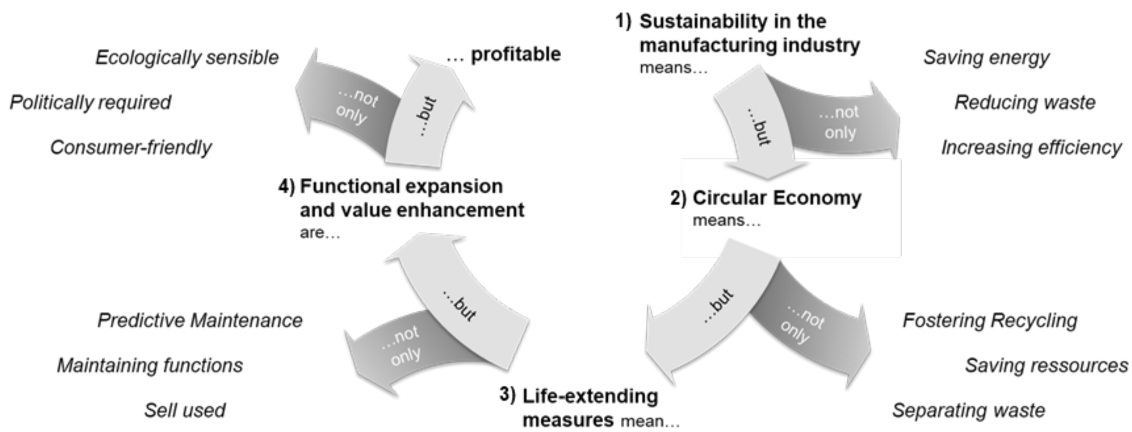

Figure 1: Aspects of a profitable circular economy: circular economy should not only reduce consumption but enable economic sustainability by value enhancement [10]

2.2 Re-Assembly

RIESENER ET AL. define Re-Assembly as "the replacement of components with refurbished and newly developed components for the short-term provision of a product that is at least as good as new with a warranty and, if necessary, an extended range of functions, while at the same time preparing for the recycling of the components" [11]. This definition overlaps in some aspects with the definition of remanufacturing by POTTING ET AL. who define remanufacturing as the use of discarded products in a new product with the same function [9]. Thus, the two terms must be distinguished from each other. As with remanufacturing, Re-Assembly involves the reconditioning of components to providing as-new products [12]. In contrast to remanufacturing, Re-Assembly is also characterized by an enhancement in function or value in defined cycles during the lifetime of the products and high industrial scaling in specially designed factories. In particular, cycle planning does not start at the end of a product's life cycle, but already during the design of new products. [3] Although design for circular economy is already elaborated in literature Re-Assembly extends the concepts by focusing on the design for industrialized or scalable implementations of upgrades in the usage phase.

2.3 Related Research

Due to the term's novelty, the literature lacks proper coverage. Only a few authors describe the term Re-Assembly as it is defined in this paper. Since Re-Assembly shares multiple aspects with remanufacturing, upgradeability, Product-Service Systems (PSS), and continuous innovation, this chapter has been supplemented with relevant research from these areas. The approaches are summarized in the following.

SCHUH ET AL. describe the idea of Re-Assembly and explain requirements for the industrialization of the concept. They introduce an "Upgrade Re-Assembly Factory" and elaborate necessary aspects and elements for this factory concept to be climate-neutral and profitable under current conditions. The article includes process designs, elements of factory planning and enabler to operationalize the concept such as the digital product pass. It also elucidates how to transform a brownfield factory. [3]

RIESENER ET AL. investigate the enablers of Re-Assembly in an automotive context. The paper summarizes related concepts that support the definition of the term which include continuous innovation, upgradeability, open architecture products, and remanufacturing. According to them, Re-Assembly products are planned to be upgraded and continuously innovated from the development phase on. Thus, the product's architecture, the hardware interfaces and business model need to be adapted. [11]

In the context of remanufacturing, LUND identifies seven key product attributes for remanufacturing. According to this, the product must not be consumed by its users, it must be possible to dismantle it and restore it to its original state by repairing, refurbishing, or replacing the components. It also requires technological stability, as well as structure and design. From an economic point of view, the used product must have sufficient residual value and there must be sufficient supply of used products and demand for remanufactured products on the market. [13]

PARKINSON AND THOMPSON argue that an upgrade to the latest technical standard may be necessary to prevent obsolescence, rather than necessarily a refurbishment to the original condition. For this reason, they suggest a return to "as-new condition". [14] In this context, HOLLANDER ET AL. states that obsolescence does not necessarily have to be technological, but is ultimately a perceived loss of value. [15] KAMRAD ET AL. emphasize that obsolescence can be reversed with upgradeable products. Suitable products are characterized by a high value, different technology progress rates of the components and high redesign costs. [16] VIMAL ET AL. state that the upgradeability of products is an important criterion for circularity [17]. By upgrading products, the functional capabilities or cosmetic condition of a product can be improved compared to the original design. The ability to upgrade enables significantly longer use and prevents a product from becoming obsolete. [15]

In order to adapt products to rapid technological development and changing customer preferences at the same time, CHIERICI ET AL. suggest offering a periodic upgrade of products in the course of remanufacturing as part of a remanufacturing PSS (Product-Service-System). This requires these products to be designed to be robust against future uncertainties. In addition, a fundamental willingness on the part of customers and companies to accept such business models need to be implemented. [18] In this context, RIESENER ET AL. and PERAU ET AL. identify relevant artefacts for the implementation of continuous innovation for technical products and characterize this innovation approach [19,20]. In this context, it should be noted that continuous innovation explicitly refers to products that have already been launched on the market but are still being continuously improved and upgraded.

COPANI AND BENHAM propose a similar system as Re-Assembly under the term "remanufacturing with upgrade PSS for new sustainable business models". However, neither the planning from the product design and development phase nor the industrial scaling in own factories is discussed. The authors note that the prerequisites in particular still need to be researched. [21]

In conclusion, for a lot of attributes of Re-Assembly there is already existing research. However, it is rarely investigated in combination or under the term “Re-Assembly”. Existing literature concerning Re-Assembly does not offer a sufficient embedding in existing research and does not focus on guidelines for the industry. In order to tackle this, this paper condenses the characteristics of related concepts into guiding principles to create a common understanding of Re-Assembly, aims to facilitate the implementation in practice, and fosters further research. Regarding this, the paper focuses on economic and ecological sustainability.

3. Research approach

Based on the categorization of literature studies according to COOPER [22], this paper aims to synthesize the elementary characteristics of Re-Assembly from already better-defined and related topic areas and, building on this, to conclude about holistic guiding principles for the industry. The applied research approach consists of four steps that are displayed in Figure 2.

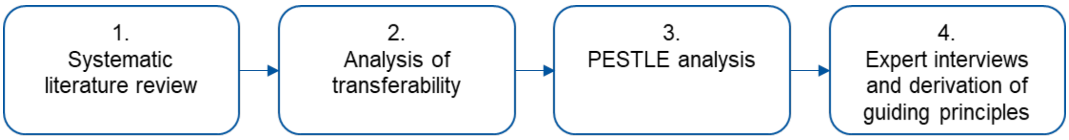

Figure 2: Research approach for delimiting “Re-Assembly” and deriving guiding principles for the industry

First, an exploratory search is used to identify related topic areas, which then forms the basis for a systematic literature search, for which the search process according to VOM BROCKE ET AL. [23] and the STARLITE method according to Booth [24] are applied. The search originated from existing literature on Re-Assembly and continued with linked topic areas that are mentioned in the same context and whose relevance is verified by comparing it to the existing literature. The identified topic areas are “Remanufacturing”, “Upgradeability”, Continuous Innovation” and “Product-Service-System (PSS)”. The literature research is conducted with the databases of Web of Science, ScienceDirect, SpringerLink, and IEEE Xplore. It results in 20.815 publications that are examined regarding their relevance by applying the method of KIRCHNER AND MEYER [25]. After the following “backward search”, this results in 89 relevant publications.

The second step is to synthesize characteristics from the identified topic areas that are transferable to Re-Assembly. The approach of the analysis was inspired by the transferability analysis of healthcare-related studies. As described by PERLETH, both the internal and external validity of study results must be checked. When checking the internal validity, systematic errors within the study are first identified. This is followed by the actual examination of transferability with external validity. This involves analyzing which effects and factors influence the study and which differences can be attributed to different conditions. [26] The transferability of results is also used as an evaluation criterion for qualitative studies. In the concept for evaluating qualitative research by STEINKE, the limits of the transferability of results to other contexts are addressed as a "limitation". Therefore, transferability can be determined by the congruence between the original and new context. [27] Thus, two major criteria are used to check the transferability of identified characteristics for Re-Assembly: (1) the fundamental assumptions regarding prerequisites, goals and fields of application are similar in both contexts; (2) there are no limitations in the new context that contrasts with the fundamental idea of the approach.

In the third step, a framework is created to structure the identified transferable characteristics. This is done with the help of the PESTLE framework (Political, Economic, Social, Technological, Legal, Environmental). According to KAUFMANN, the PESTLE analysis is a variant of the environment analysis and identifies the opportunities and risks that arise from the company's integration into the bigger picture. [28] The framework is extended by a second dimension, including the perspectives “product”, “business model”, “company” and “market”, which structures the search for characteristics in more detail. The perspectives cover the main dimensions for Re-Assembly and are derived from the Re-Assembly enablers by RIESENER ET AL. [11].

In the final step, the results are validated with the help of semi-structured interviews with industry experts, and guiding principles are formulated. For the interviews, a guideline according to LOOSEN was developed [29] which is also subdivided into the parts “product”, “business model”, “company” and “market”. In order to have a broad and interdisciplinary perspective on the identified results, the experts that have been interviewed, cover the industries of machinery, home appliances, and automotive.

4. Results

In this chapter, the results of this research approach are displayed. First, existing topic areas from the literature are explained which form the basis of the term Re-Assembly and were used as search terms in the literature review. Subsequently, the structuring through the PESTLE analysis is presented. Finally, the guiding principles for the industry for establishing Re-Assembly are introduced.

4.1 Characteristics of Re-Assembly

From the relevant literature, four topic areas were used to describe the characteristics of Re-Assembly. The topic areas that originate from the exploratory search are briefly described in the following.

- **Remanufacturing** is the use of discarded products in a new product with the same function [9].
- **Upgradeability** in the context of this work is the feasibility of technically updating a system and its continuous ability to be renewed and improved [30].
- **Continuous product innovation** is a knowledge-based process that allows product improvements throughout the product life cycle [31].
- With a **product-service-system (PSS)** approach, the products are usually leased or rented and not sold to the consumer. Maintenance, overhaul, and upgrades of the physical product are the responsibility of the manufacturer. [32]

The basic requirements for remanufacturing, as the most comparable concept to Re-Assembly, were already defined by LUND in 1985. A more detailed summary based on seven criteria was provided by GUIDE in 2000. Beyond the adaptation of PSS, take-back concepts, new business models, and upgrades, the basic criteria do not appear to have changed, as they are cited directly or indirectly in most relevant publications on remanufacturing. There is also a basic consensus in the literature on the prerequisites for upgrades and continuous innovation. This enables an almost complete definition of Re-Assembly using the existing topic areas.

Through a systematic consolidation via thematic clustering and summarizing as described by HANEEF [33], 36 characteristics have been identified within the literature research. They describe overlaps of Re-Assembly with the topic areas described above and are used to characterize the term Re-Assembly. The PESTLE analysis facilitates the structure and clarity of the identified characteristics. The results are presented in Figure 3.

	Corporate-Political	Economical	Social	Technological	Legal	Ecological
Product	Marketing strategy (5)	Product fit (1)	Customer acceptance (1)	Product fit (1, 2)	Legal transparency (1)	Sustainability assessment (1)
	Brand identity (5)		Priority shift product development (1)	Product design (1, 2)	Upgrade approval (2)	
				Compatibility of upgrades (2)	Material permissibility (1)	
				Usage transparency (3)		
Business Model	Cooperation with partners (1)	Reverse logistics (1)	Customer acceptance (4)	Reverse logistics (1)	Financial incentives (1)	Lifecycle costs (1, 3)
		Cost competitiveness (1)		Functional & ecological added value (1, 2)		Increased utilization by subscription (4)
		Cannibalization (1)				
		Ownership structure (4)				
Company	Network strategy (1)	Investment risks (1)	Knowledge management (1)	Complexity management (2, 3)	Authorization (e.g. for handling "waste") (1)	Holistic sustainability (1)
			Corporate culture (1)	Formalization of continuous innovation (3)		
Market	Business ecosystem (1)	Ecosystem for continuous innovation (3)			Cooperation agreements (1)	Availability of sustainability data (1)

The identified attributes above are originated from the following topic areas and their corresponding, exemplary literature sources:

(1) Remanufacturing	[11, 13, 14, 33]	(2) Upgradeability	[15, 17, 18, 28]	(3) Continuous Innovation	[19, 20, 29]
(4) Product-service -system	[21, 30]	(5) Interviews			

Figure 3 - Characteristics of Re-Assembly derived from related topic areas and industry interviews

In the "Product"- line comparable characteristics are displayed that address the characteristics of suitable products as well as their architecture. 13 characteristics can be connected to this category. The "Business Model"-line refers to the enablers of Re-Assembly that are related to the applied business model. It includes especially changes compared to a transactional business model in the context of the linear economy. Eleven characteristics are sorted into this category. The "Company"-line focuses on the challenges the manufacturer of a Re-Assembly product will face regarding their supporting processes and interactions with external stakeholders. Eight characteristics are identified. The last line "Market" concentrates on the company's environment in the market and the necessary ecosystem that the company has only limited influence on. Four characteristics are related to this category. All characteristics are linked to the topic area they are derived from with corresponding indices. Consequently, Figure 3 helps to link Re-Assembly to existing topic areas in practice and supports the embedding of the term in the literature.

4.2 Guiding principles for Re-Assembly

In the following, the resulting characteristics displayed in Figure 3 are condensed into five guiding principles via interpretative consolidation as described by HANEEF [33] to provide guardrails for users and increase the manageability in a practical context. The principles differentiate from the categories of Figure 3 to fit their relative significance. The "Product"-line is divided into two guiding principles, "product suitability" and "product adjustments". The "Business Model"-line leads to the guiding principle "business model suitability". The "Company"- and the "Market"-category are combined and result in the guiding principle "business process adjustments" after clustering, which also resulted in the creation of the principle "sustainability understanding" from all ecological characteristics to emphasis the ecological orientation of Re-Assembly.

4.2.1 Product suitability

Products are suitable for Re-Assembly if they are not consumed and if a sufficient value can be returned to the manufacturer. The resources and capital required for remanufacturing and Re-Assembly are only offset by adequate added value if the product value is high. Re-Assembly cannot be profitable for cheap products. The product's value, originating from the product's basic functions, needs to be stable over time so that the product's concept does not become obsolete. [13,14] As with upgradeable products, Re-Assembly products profit from fast technology evolution or a frequent optical or emotional demand for overhauling. Together with high costs for redesign, this increases the economic and ecological attractiveness of a Re-Assembly concept. [16,30] Moreover, to enable the scalability and profitability of Re-Assembly, products need to be sufficiently available in the market regarding quantity and quality [13]. In essence, this leads to the following guiding principle:

Re-Assembly products need to be highly available in quality and quantity and be stable regarding their functional value over time, but face a decline in value due to changes in technological or emotional requirements.

4.2.2 Product adjustments

Re-Assembly products are developed under different premises compared to products in a linear economy. Along the dimensions of cost, time and quality, the products are developed for disassembly, repairability, and upgradeability, which can result in an over-engineering of the product's design and functions as well as in high requirements for modularization or changes in material. [34,3,17] In addition, durable components set new requirements for innovation management due to the extended time horizon. Continuous innovation is now applied to existing products in the usage phase with their corresponding innovation boundaries. Thus, product development requires other tools to enable the anticipation of future technology, regulatory, or social changes. [35,36] Moreover, tracking the product's usage is crucial to support the upgrade planning by predicting the product's quality and quantity. Therefore, products are developed with sufficient IoT-technology, which is not sensible for every product. [37,38] In essence, this leads to the following guiding principle:

Re-Assembly products necessitate a rethinking and redesign to enable upgradeability, durability, and predictability, leading to new architectures and modularization approaches, which need to be anchored in innovation management and product development.

4.2.3 Business model suitability

Due to the increasing share of added value of service activities with Re-Assembly, PSS becomes more relevant to support the company's transition to a solution provider. A suitable business model, e. g. a subscription model, can be an enabler of Re-Assembly approaches since it eases the handling of reverse logistics, product ownership, or data availability [11]. However, the configuration of such a new business model is challenging. For example the quality expectations of customers and their willingness to pay must be taken into account [39]. In the case of remanufacturing, the impact of pricing on the availability of products on the market and cannibalization effects with regard to the newly produced products must also be considered [40]. In addition, the product ownership that remains at the OEM leads to a capital lock-up risk that may require financing partnerships [41]. Finally, the transition to a PSS depends on the integration into the company's identity and strategy, acceptance by the customer, and economic and ecological sustainability [42]. The advantages of the transformation need to be effectively communicated to internal and external stakeholders. In essence, this leads to the following guiding principle:

The adoption of Re-Assembly approaches leads to an extensive need for business model transformation, which requires the careful orchestration between several stakeholders and company goals.

4.2.4 Business process adjustments

A Re-Assembly approach influences not only the product and the business model but also the way the company works. An enabler of circular business models is reverse logistics which needs comprehensive upfront planning and collaborative partnerships [32]. Collaborating with suppliers and end-of-life partners is crucial for a Re-Assembly strategy [39]. Furthermore, customer relationship needs to be modified as well by providing return incentives for the products [43]. Particularly in the context of Re-Assembly, value creation is shifting in favor of the OEM. However, for the implementation, Re-Assembly requires high-efficiency processes due to a high share of manual work while reconditioning the products and additional costs for reverse logistics [44]. This sets requirements not only for product design and pricing but also especially for production planning. Maximizing automation and utilizing usage data for improved planning of upgrade processes are central aspects [18,37]. Moreover, due to the factual creation of new product variants through the introduction of second-lifetime products the internal complexity increases [45]. Especially, when it comes to the controlling of sustainability and profitability a new dimension for product portfolio management needs to be introduced. Another topic to consider is the admission of the usage of used components and the subsequent modification of products that are subject to legal authorization (e. g. for vehicles) which can be an issue depending on the market and industry. In essence, this leads to the following guiding principle:

Re-Assembly requires major revisions of adjoined business, production, and supply processes and principles.

4.2.5 Sustainability understanding

The main goal of Re-Assembly is a substantial improvement in the product's and company's sustainability performance in regard to economic and ecological aspects. Thus, an assessment of the ecological is crucial for decision-making during product and upgrade planning. This raises the issue of supply chain data availability to operate a Re-Assembly concept credibly. [46,47] However, this can also exhibit synergy potential with upcoming reporting duties in Europe. Moreover, Re-Assembly means applying other aspects of circular economy and sustainability and brings along fundamental business transformations regarding the company's culture, values, employee training, strategy definition or project prioritization [48,49]. In essence, this leads to the following guiding principle:

Focusing on Re-Assembly means committing to circular economy and sustainability, thus the company's way of thinking and strategic development perspectives should be adjusted accordingly.

5. Summary and outlook

This paper aims to establish Re-Assembly as a new R-strategy in industry and research. For this, the relevant characteristics of Re-Assembly were investigated based on key characteristics from related topic areas. The investigation is based on a systematic literature review regarding these topic areas and covers a subject matrix that was spanned by a PESTLE analysis. The derived guiding principles show areas of attention, challenges, and possible solutions and facilitate the creation of a common basis for dealing with Re-Assembly. However, it must be noted that not every company or product is compatible with a Re-Assembly approach.

Finally, the prospects of success of possible Re-Assembly business models need to be further investigated as well as the effects of the R-strategy on the social aspects of sustainability. Moreover, the cost drivers of Re-Assembly may be considered in more detail in future research. Research may also be conducted on how regulations can be used to support circular business models in a targeted manner as especially the interviews showed a lack of incentives for companies.

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