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Concept And Exemplary Application Of Industrialized Re-Assembly To An Automotive Use Case In The Context Of Circular Economy

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Abstract

To reach set climate goals recent paradigms of production need to be reconsidered. Within the automotive industry, approaches like electric mobility focus on the use phase. However, the production of an electric car is resource and energy intensive, which diminishes the ecological advantage of electrification in the use phase. Established approaches aiming for the production phase often involve saving energy or resources, which is in a single-digit range when it comes to the reduction of emissions. In contrast to that, applying the concept of Circular Economy can reduce the ecological impact of products over their lifetime significantly. This paper introduces Re-Assembly as a plannable concept to extend the lifetime of products while reducing emissions and increasing the margins for the OEM. By combining the concept of Re-Assembly with other R-strategies, this paper aims to demonstrate the ecological and economic potential of circular business models, especially in the automotive sector. This is done by introducing the results of a use case and deriving specific enablers for the concept. The resulting enablers can be understood as fields of action for establishing Re-Assembly in practice.

Keywords

Sustainability; Re-Assembly; Remanufacturing; Circular Economy; Production

1. Introduction

In the context of the sustainability transformation, manufacturing companies are on the edge of a paradigm shift. According to the Circularity Gap Report 2023, 70% of the global greenhouse gas emissions are produced by the handling or usage of materials [1]. To limit the consequences of climate change to a temperature rise of 1.5 degrees Celsius a maximum of 400 Gt of CO_2-equivalences can be emitted, calculated from the beginning of 2020. With constant emissions, this CO_2-budget will be depleted in a few years [2]. At the same time, the manufacturing industry is characterized by over-production and over-capacity. For instance, a tooling machine has a 34% capacity utilization on average [3]. In the automotive industry, it is common to produce a disproportionate variety of vehicles that result in only 20-30% of profitable variants [4]. Focusing on the automotive example, the profuseness becomes clearer when looking at the usage phase. Private vehicles are only used with 1.5% of their loading and time capacity [5]. Furthermore, the mobility shift, driven by the EU's ban on internal combustion vehicles [6], is leading to an increased production of electric vehicles with increasing battery sizes. This leads to a significantly worse environmental footprint of an electric vehicle in production compared to an equivalent combustion vehicle [7]. In summary, there is a high level of overproduction, overcapacity and resource consumption in the automotive industry.

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A possible solution for these issues is the concept of Circular Economy and the associated R-strategies. This paper aims to introduce the concept of Re-Assembly as a possible strategy for the transformation of the automotive industry. By giving an overview of approaches from science and practice the paper demonstrates the ecological and economic potential of Re-Assembly in combination with other R-strategies and summarizes with the main enablers for this concept.

In the following chapter, the basic terms are defined and relevant research is summarized. Chapter 3 contains a description of the paper's research approach. In Chapter 4 the overall concept of the latter, its enablers alongside its potential are outlined. Chapter 5 concludes the paper with a summary and outlook.

2. Fundamentals

In this chapter, the basic terms "Circular Economy" and R-strategies are defined and differentiated. Subsequently, related work is summarized.

2.1 Circular Economy and R-strategies

Circular Economy is defined as an economic model that is able to decouple economic growth and resource consumption by using them in circulation. In contrast to that, the linear model is based on a "take-make-waste pattern". It is built on the assumption of cheap and easily accessible materials and energy. [8] Ellen MacArthur visualized the two fundamental cycles of Circular Economy, the technical cycle and the biological cycle, as shown in Figure 1. The cycles display how the linear model can be transferred to a circular model [9].

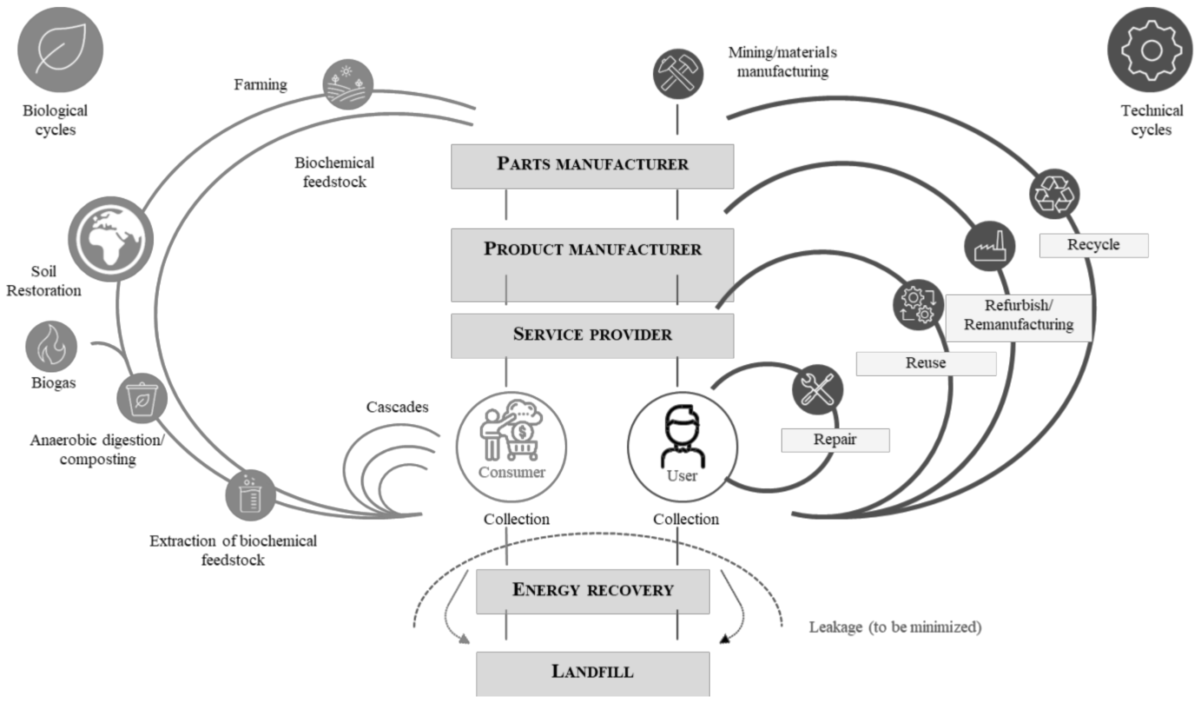

Figure 1: Butterfly model displaying the cycles of Circular Economy by Ellen MacArthur [9]

However, when reviewing these cycles the prioritization of the circles and their goals besides ecological sustainability do not become clear. The linear model, which is used today, has worked so well because it was economically beneficial. To be successful the circular model needs to become comparably profitable. Sustainability is already pursued today in the form of energy saving, efficiency and recycling. Though, life-extending measures and functional product expansions have potentially more ecological impact while being profitable as well. So, Circular Economy has to be a tool to align economic and ecological goals. Figure 2 shows which approaches need to be considered to make profitable sustainability work. This paper uses these approaches to introduce Re-Assembly as a new strategy to achieve this goal.

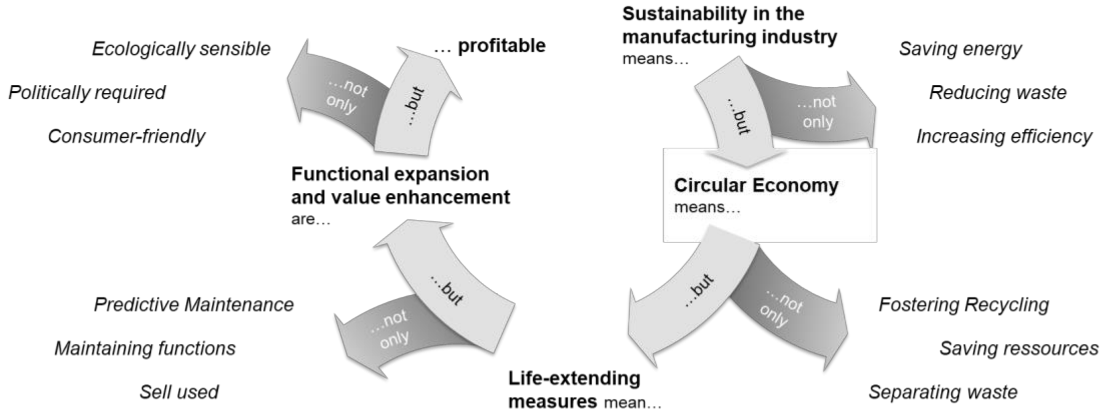

Figure 2: Aspects of a profitable Circular Economy [10]

Re-Assembly and other R-strategies serve to operationalize the Circular Economy. An example from the automotive industry demonstrates the ecological and economic added value of R-strategies. It shows that remanufacturing requires up to 80 % less energy than the production of new components [11]. In addition, water consumption is reduced by 88 % and the amount of waste by 70 % [11]. In this example, remanufactured parts are up to 40 % cheaper than new ones [11]. This means that customers can be offered an economically viable way to extend the lifetime of their product, saving further resources and emissions. Another advantage is the reduction of dependence on primary resources. Closed material cycles can achieve material savings and industries such as the automotive industry benefit from this in particular [12]. Since Re-Assembly shares and extends the ideas of remanufacturing, it is likely to have even greater potential.

Various R-strategies have been defined by several authors to help operationalize the concept of Circular Economy. In the following, this paper will refer to ten R-strategies that have been defined by Potting et al. and are listed in Table 1. Potting et al. have ranked them so that the strategies at the top of the list are those that embrace circularity the most. They require less energy and effort for realization and therefore have less impact on the environment [13].

Table 1: R-strategies by POTTING ET AL. [13]

R-strategy	Description
Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
Rethink	Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market)
Reduce	Increase efficiency in the product manufacture or use by consuming fewer natural resources and materials
Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
Repair	Repairs and maintenance of defective product so it can be used with its original function
Refurbish	Restore an old product and bring it up to date
Remanufacture	Use discarded product or its parts in a new product with the same function
Repurpose	Use discarded product or its parts in a new product with a different function
Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
Recover	Incineration of materials with energy recovery

However, referring to Figure 2, remanufacturing is the most noteworthy R-strategy despite its location in the middle of the list. Remanufacturing has the potential to optimize the ratio between renewed input and product value. Due to the usage of existing components and modules, resources, energy and value can be preserved and enhanced. As a value generating process remanufacturing enables the industry to be sustainable and profitable, build a circular business model and maintain employment. Other R-strategies prevent or reduce value creation since they are based on minimizing consume or restricting the maintenance of the original value of the product.

This paper introduces the term "Re-Assembly" as an additional R-strategy and advancement of remanufacturing that aids to operationalize Circular Economy. Re-Assembly is 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. To distinguish this from remanufacturing, it is crucial to emphasize the upgradeability of the product. In addition, unlike remanufacturing, Re-Assembly should be plannable and carried out on an industrial scale. By considering all product modules and applying other R-strategies on a module level as well, this aims to minimize the product carbon footprint over the entire life cycle of the product and to close the loop for all resources used. To summarize, Re-Assembly aims at an industrial and scalable production of products and modules for lifetime extension and value enhancement in an "Upgrade Circular Economy".

2.2 Related work

This chapter provides an overview of related terminologies to help outline the field of Re-Assembly. It shares the shown characteristics with them.

LANGE explains that **remanufacturing** offers great savings potential in terms of resource efficiency and energy efficiency. Although transport and reprocessing of the components generate additional emissions and require additional resources, these are significantly lower than those required for a new production. In addition, remanufacturing often requires less energy than recycling with subsequent new production of the component. Remanufacturing results in significantly lower production costs, which leads to a higher profit margin and can be passed on to the customer in the form of lower purchase prices if required. [14]

VAN LOON ET AL. name product categories where **remanufacturing** can achieve savings. Remanufacturing is suited for products that create a large part of their environmental impact during manufacturing. If the majority of the environmental impact is caused during the use phase, it is more expedient to substitute these with new, more efficient products. For products that lose efficiency over their lifetime and use more energy as a result, it may be better to replace them with new ones than to extend their lifespan. [16]

KAMRAD ET AL. describe the current concept for **upgradeable products** and developed a model to indicate under which circumstances this concept is profitable for companies. The concept divides the product into stable and improvable components. Improvable components can be exchanged and replaced by new ones with new features. This enables the customer to always be up to date with the latest technology without having to purchase a completely new product. In addition, only some of the components need to be adapted during development, which in turn reduces the time and cost of the development process. From an environmental perspective, this can reduce waste from obsolete products. The authors mention various scenarios in which the use of upgradeable products is suited for companies, including small market sizes, high production costs or different innovation speeds of individual components. [17]

PENG ET AL. present requirements for the development of **Open Architecture Products** (OAPs). OAP are in demand due to growing market requirements in terms of adaptability and cost efficiency and allow other manufacturers to adapt existing products to meet customer needs. An OAP is enabled by an adaptable design process; commonality and modularization are therefore not sufficient. The authors introduce a design process and give an example of an electric vehicle with an open architecture concept that can be adapted during its life cycle. [18]

LIANTO ET AL. try to show the different aspects of **Continuous Innovation** (CI) with their study. CI is understood as an innovation process that continuously and in a structured way generates innovations so that sustainable and growth can be achieved in the long term. This enables companies to quickly adapt to a fluctuating market and new customer demands. With CI development times can be reduced and the frequency of new products increased, which helps companies to remain competitive. In their study, the authors identify fundamental capabilities that enable CI. Among them are mainly intangible resources such as knowledge management or the social environment in the company. [19]

Re-Assembly as a term combines and enhances the characteristics of the established approaches shown. It serves as a overarching concept to describe an industrial and scalable (re-)production of products and modules for lifetime extension and value enhancement in an "Upgrade Circular Economy". The literature so far lacks a suitable compilation of enablers for Re-Assembly. To derive a conceptual framework this paper presents the enablers of Re-Assembly in the following.

3. Research approach

This paper is designed as a qualitative and exploratory case study as described by [20] that draws on both literature and semi-structured interviews with researchers of the Laboratory for Machine Tools and Production Engineering WZL of RWTH Aachen University and a local automotive start-up, which focuses on a circular business model. The central research question was how Re-Assembly could have an ecological and economic impact on the automotive industry. The economic and ecological potential of the concept is demonstrated by referring to industry examples and literature on related concepts like "remanufacturing", "upgradeable products", "open-architecture-products" and "continuous innovation". The research is supported by the findings of the "Re-Assembly-Factory case study" of the Machine Tool Colloquium of Aachen (AWK) in 2023. The AWK is an international platform for industry and research collaboration that is hosted by the WZL since the year 1948. In 2023 the topic was the transformation to a value-enhancing Upgrade Circular Economy. Part of the program were multiple case studies to demonstrate current research findings. One of those was the "Re-Assembly-Factory case study" which focused on the practical demonstration of a Re-Assembly factory concept in the automotive sector. The introduced potentials have a theoretical character and are to be understood as impulses for further research.

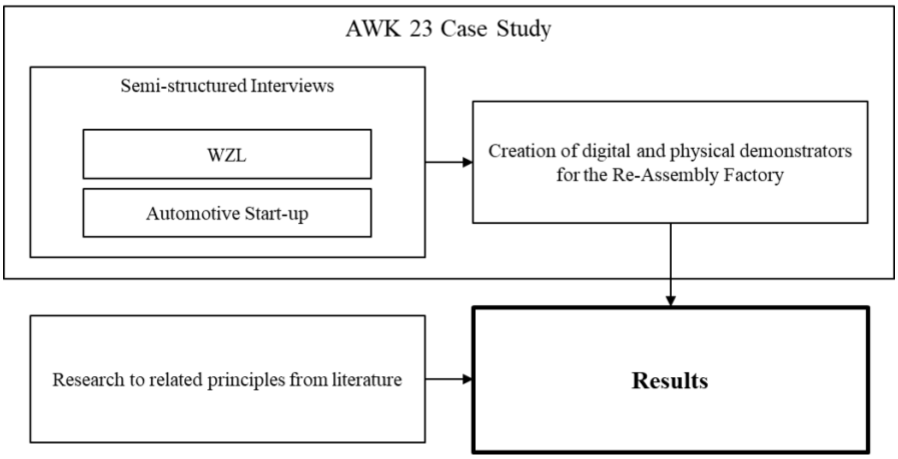

Figure 3: Research approach for determining relevant enablers for Re-Assembly

4. Re-Assembly Concept

This chapter aims to outline how a Re-Assembly concept can be established in practice. First, the Re-Assembly Factory use case is described. Second, the enablers for Re-Assembly which have been derived from that project are outlined.

4.1 Re-Assembly Factory at RWTH Aachen Campus

In the course of the AWK, a pilot project for a Re-Assembly Factory (Figure 4) was presented. In particular, the reassembly of the vehicle's outer skin components was shown. The first step was to dismantle the body parts from the vehicle. The disassembly was carried out with little effort since many components are fastened with quick-release fasteners. What remains is the so-called 'core', the part of the product that remains after disassembly [21], e.g. the vehicle frame in this case. This consists of components that have a long lifetime. The preservation of such components leads to emissions savings.

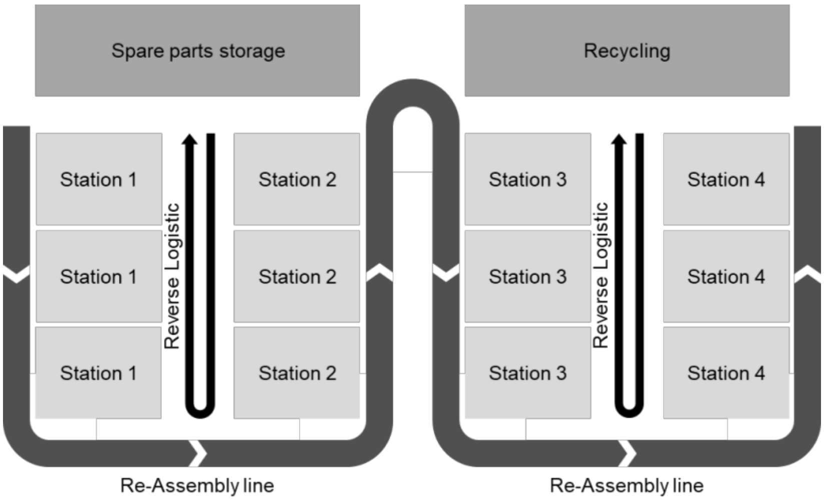

Figure 4: Concept of an Upgrade Re-Assembly Factory

During disassembly, the dismantled components can be assessed with regard to their quality and, based on this assessment, can be fed to the appropriate further processing [21]. Here, mainly remanufacturing and recycling approaches are considered. In particular, remanufacturing can take place directly at the same factory site or even directly on the assembly line. This reduces transport costs and can enable economic remanufacturing processes. In this use case, the vehicle’s seats were presented as an example of remanufacturing. The lifetimes of individual components of the seat can differ significantly. Remanufacturing allows to fully utilized the differing lifetimes of the components. This is achieved by replacing components after their useful lifetime while others can still be used. This leads to savings in emissions and resources.

In the second process station, new components - either remanufactured or newly produced ones, depending on customer requirements - were re-assembled. New components with functional enhancements can not only preserve the value of the original product but also increase its value [21]. Such extensions may be cameras or sensors for assistance systems. In the use case, other components such as the dashboards or headlights were also replaced. The final step was to test the re-assembled product. Here, the product must fulfil at least the same requirements as a comparable new product. If this is also given, the product can be delivered. [21]

During this use case, the enablers of Re-Assembly were identified and displayed via digital demonstrators. The results are incorporated in the following chapter.

4.2 Enablers for Re-Assembly approaches

The following chapter deals with several enablers for Re-Assembly concepts that have been identified through the case study. It serves as list of topics to engage with to establish Re-Assembly in practice.

4.2.1 Flexible Factory Concepts

Although Re-Assembly is considered “plannable” when compared to remanufacturing this does not result in a similar level of production certainty as it is usual in scalable linear production. In the context of Re-

Assembly “plannable” means that the upgrades and revision of products are intended since the product development. However, due to the longer lifetime of the product, the uncertainty regarding the condition is increased. Different customer requirements over the period of usage add to this tendency as well. Consequently, every upgrade cycle differs from product to product and which upgrade cycle the product is currently in. Although Re-Assembly has to be industrialized to unlock its full economic potential, a regular linear factory concept is not sufficient. Therefore, a matrix organization has been used in the described case study (Figure 4). A matrix factory concept represents a compromise between the flexibility of a workshop and the scalability of a line production [22]. This concept helps to level out the remaining uncertainties and enables spontaneous adaptations to unpredicted deviations regarding the product's condition. It also eases the organization of reverse logistics streams.

4.2.2 New Modularity

To enable Re-Assembly concepts and foster the ecological sustainability of products the modularization of products needs to be revised [25]. While in the past the goal of product modularization was cost reduction and the management of variant complexity [26] the dimension of sustainability establishes as a new factor in product development. Thinking about recycling, it is beneficial to design modules with the aim of easy separation of materials. Regarding Re-Assembly modularization has the goal to minimize disassembly effort by designing modules taking into account different lifetimes and the accessibility of components. This can result in a fundamentally different product architecture. Referring again to the term “plannable Re-Assembly”, thinking ahead in product development plays a vital role in enabling efficient Re-Assembly concepts.

4.2.3 Open-Architecture Products

When thinking about upgradeability and new paradigms for modularizations the concept of open-architecture products comes into mind. Originally a concept from software development, it represents the idea of enabling third-party products to be compatible with the product. The main product serves as a platform on which a variety of other products work as components, comparable with an operating system of a smartphone and its applications. This has the potential for more customization with significantly less internal complexity. However, the producer needs to open up and adequately aggregate constructional data to third parties. Furthermore, the establishment of new hardware interfaces, that are potentially more complex and expensive, and security standards are prerequisites.

4.2.4 Hardware Interfaces

Reconditioning used products may be not profitable if the process is too complex. To reduce labor costs and takt time in a Re-Assembly factory the products need to be disassembled easily. While automated disassembly can be complicated due to the variety of conditions in which the products are returned to the factory, manual disassembly can be expensive. Especially if Re-Assembly factories are located in high-wage countries to enable efficient and ecological reverse logistics the disassembly process must become highly efficient. One option to support that is to modify the product’s hardware interfaces. While conventional products often have inseparable interfaces which are glued or welded circular products need to be dismountable without damaging a component. This can be done by reintroducing quickly detachable screw connections or similar interfaces. The resulting higher costs are compensated by the product's extended lifetime.

4.2.5 Digital Product Pass

The most effective tool to eliminate the uncertainty of a Re-Assembly system is the utilization of usage data. A digital product pass serves as an enabler to collect, store and present such data to the relevant stakeholder. The product pass collects data through the entire lifecycle. This is especially reasonable on the level of components. The pass stores data about the product's architecture, the materials used, information for maintenance, energy and emission data to calculate the product carbon footprint [23]. It collects usage data to enable predictive maintenance or to foster further customization. Every component has its own set of data even if assembled into another product which is crucial for products that rely on homologation. Moreover, the digital product pass supports the workload planning for the Re-Assembly factory by calculating the upgrade scope for the next Re-Assembly appointment with a use of usage and customizing data. However, due to the storage in a cloud system, the issue of data privacy must be clarified beforehand.

4.2.6 Homologation

One issue when trying to upgrade products, especially in the automotive sector, is homologation. Modifying or upgrading a safety-relevant component can lead to the invalidity of the vehicle's homologation. One approach to tackle this is to pre-homologate possible component combinations so that if the product leaves the Re-Assembly factory with an upgrade it is already certified. However, this complex legal issue should not be discussed further here. Rather, this should be an appeal that the homologation processes of circular products must change in the future.

4.2.7 Subscription Business Models

Although it is possible to operate a Re-Assembly concept with a transactional business model, there are several reasons to switch to a subscription model. In general, to foster the transformation to a Circular Economy incentives need to be created for both customer and producer. Subscription models are characterized by the ownership of the product which remains at the producer [24]. The customer pays for the usage of the product. This leads to several advantages that synergize with Re-Assembly concepts. Firstly, the producer has an intrinsic motivation for the product to have a longer lifecycle and develops more robust products. Secondly, due to the ownership, the producer keeps the right to retrieve the products for an upgrade to extend the lifetime of the product. Thirdly, it becomes easier to get the right to utilize usage data. Moreover, customers benefit from periodically lower payments instead of high initial investment costs, the value preservation and up-to-dateness of the product.

5. Summary and outlook

This paper addresses the paradigm shift needed in manufacturing companies in the context of the sustainability transformation. To tackle this challenge the paper proposes the concept of an Upgrade Circular Economy with the associated R-strategies and the concept of Re-Assembly. This has been done by referring to related research and practical experiences from the authors. The case study and interviews that have been carried out revealed the challenges and prerequisites of the concept. With the provided input this paper summarized and outlined relevant enablers of Re-Assembly. Flexible factory concepts are needed to deal with the uncertainty of the product's condition which can be reduced by collecting life cycle data via a digital product pass. To enable upgradeability products need to be designed with quick-release interfaces and modularized for disassembly and compatibility with third-party components. Subscription business models can help to establish planned upgrade cycles and pre-homologate new component combinations. More research is needed to investigate how the enablers of Re-Assembly need to be designed in detail. Furthermore, it needs to be explored to what extent the applicability of Re-Assembly depends on the industry. Lastly, it must be emphasized that Re-Assembly is still a concept that needs to be further developed and tested in practice. It holds significant potential when it comes to circularity but represents a major shift with regard to the predominant concept of linear economy.

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Biography

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