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Supporting product development with a practical tool for applying the strategy of resource circulation

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Abstract

In their pursuit of a transition towards a circular economy, manufacturers are challenged to implement abstract principles of circularity in product development. Therefore, this paper mentions strategies to enhance resource-effectivity by design. The specific industry case of Remeha, a manufacturer of domestic boilers, focuses at the strategy of resource circulation. To apply this strategy, product engineers are supported with information about relations between product characteristics and reverse cycle processes. A design support tool is developed to represent this information through substantive guidelines for development decisions. A usability test with the target group has verified that this tool provides applicable insights on developing new product solutions.

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Keywords: resource circulation; product development tool; circular economy; industry application.

1. Introduction

An increasing number of companies acknowledges the importance of the circular economy, enticed by the long-term prospects of more reliable resource availability, reduced costs, or new business opportunities in a cooperative network. However, initiating the necessary changes within a company to implement the principles of the circular economy is often considered a challenge. Literature, workshops and events on the circular economy generally seem to focus on articulating the necessity and prospects of the concept and less on initiating the critical first steps in the practical transition towards its realisation. Remeha, a Dutch manufacturer of boilers, is committed to adopting circular economy principles, motivated by the results of several exploratory pilot projects. They intend to concentrate their next efforts on leveraging the process of product development. Exploratory literature research has not yet revealed established methodologies that provide organisations like Remeha with an adequate, structural and actionable way to develop products for a circular economy. Therefore, this paper will discuss a possible approach to support companies implementing circular economy principles in product development. Based on an inventarisation of several strategies (section 2.3), representing different ways to enhance resource-effectivity by design, a specific design strategy was selected for further adoption (section 2.4). Subsequently, a customised tool has been developed to support the structural application of this strategy by product engineers (section 3.4). Section 2 of this paper discusses a theoretical approach on translating the general objective of sustainable development through principles of circular economy to the strategy of designing products for resource circulation. Section 3 addresses the development of the actual design support tool and the application of dedicated design guidelines for the particular corporate environment of Remeha. The conclusion in section 4 is followed by a discussion in section 5.

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2. Theory

2.1. Introducing principles of the circular economy

The circular economy is understood as a framework for interpreting and realising sustainable development. Aiming to enhance resource productivity, the circular economy proposes a system of value creation that handles resources in ways that are restorative, rather than exhaustive. Therefore, introducing a paradigm shift that allows to persist economic development while respecting environmental constraints. In pursuit of maximised resource productivity, industrial operations should be designed to restore the sources of used energy and material, to be reapplied in product lifecycles. Instead of relying solely on the large-scale accessibility of natural resources, the circular economy uses resources from end-of-life products as the primary source of economic growth.

The circular economy is built upon several pre-existing schools of thought, including the Cradle to Cradle® philosophy [1], the performance economy [2], the design principles of biomimicry [3], the industrial ecology [4], the blue economy [5], and natural capitalism [6]. An analysis of these concepts, their commonalities and synergy around circular thinking has led to the identification of five fundamental principles that are considered characteristic to a circular economy:

1. Organise reverse cycles;
2. Be resource effective;
3. Think in systems;
4. Prioritise the future;
5. Create mutual benefit.

A true circular economy embodies all five principles in coherence and acknowledges their relatedness. From a reverse perspective, these principles can be adopted by manufacturing companies to organise processes for a circular transition.

2.2. Implementing the principles of the circular economy

The principles introduced in section 2.1 can be practiced in several domains and processes in an organisation. In the context of a manufacturing company, three areas are deemed particularly relevant for implementation: product development, supply chain, and business model. These areas of implementation are inspired by the so-called building blocks from the Ellen MacArthur Foundation [7]. The business model defines what and how value should be delivered to the market, which influences requirements and priorities for product development. Alternatively, decisions for product development influence production processes, suppliers, and logistics in the supply chain. Inversely, the supply chain dictates conditions for transport and reverse cycles to which the product's design should be aligned. Although these three areas can be characterised as distinct domains, they closely interrelate. All areas need to be mobilised in an organisation to reach the full potential of the circular economy. However, within the scope of this research, product development was selected as a primary focus area to influence resource usage. This choice concentrates implementation at the core activity of the industry partner. Moreover, in the corporate environment of Remeha (section 3), product development is expected to function as a nucleus for subsequent changes throughout the organisation, connected to new product designs.

2.3. Design strategies for circular product development

To apply the abstract principles of the circular economy (section 2.1) in product development, they are translated into design strategies. This translation is based on existing design strategies from literature, including [8], [9] and [10]. Table 1 shows a concise collection of design strategies that represent different ways of enhancing resource effectivity by design. This categorised overview is meant to support the selection of strategies for a specific industry context.

Table 1. Design strategies for circular product development.

Design strategy	Including, but not limited to
Develop products for resource circulation	Disassembly and re-assembly; standardised features; modular architecture.
Develop products and services for new business models	New value propositions, integrated service development, user-centred design, monitoring product life cycle.
Develop products for a long life	Upgradable features and functionality; multiple consecutive use cycles; maintenance and repair; adaptable functionality; customisable features.
Develop products with less energy and material resources	Energy performance; dematerialised functionality; responsible user behaviour; advanced technologies and materials.
Develop products with low-impact energy and material resources	Restored resources; reduced GHG emissions; renewable energy input.

The effectiveness of design strategies, applied either individually or in coherence, depends on the characteristics of the product to be developed. For instance, designing for cascaded use cycles is only appropriate for a product that consists of biological materials while design for disassembly hardly applies to products that consist of a single component. Acknowledging such dependencies, the design strategies in table 1 are applicable to the specific industry case as described in section 3, but they are not comprehensive nor generally appropriate to every industry case.

With regard to the industry case of this research, further implementation will focus at the development of products for resource circulation. For organisations pursuing first steps in a circular transition, this strategy facilitates familiarity with the concept of closed-loop thinking, while introducing a limited impact to the organisation that can be managed within established workflows.

2.4. Develop products for resource circulation

In a circular economy, products are more than functional entities that serve a temporary need. In essence, products are resource carriers, retaining value in the form of function, material and energy. Reverse cycles are industrial processes that treat end-of-use products to recover and restore embedded value. This design strategy aims to increase resource effectivity within the scope of the technical resource flows, encompassing the processes of reuse, refurbishment, remanufacturing and recycling [1]. Table 2 shows a brief overview of these processes.

Table 2. Reverse cycles, adapted from Desai and Mital [11].

Reverse cycle	Disassembly level	Result
Reuse	Product, module, and component	Product, module or component is used again in "as is" condition, without reprocessing.
Refurbishment	Module and component	Module or component is partially repaired or replaced.
Remanufacture	Component	Components restored to "as-new" condition and used in new products.
Recycling	Material	Material used for production of new components.

The possibilities for resource circulation through each of the reverse cycles can be influenced by product development. This is the focus of the "develop products for resource circulation" strategy. This strategy considers four specific approaches to promote resource circulation by design. First, a product's structural design can allow for easy disassembly and reassembly to enable recovery of embedded resources with maintained integrity. Second, a modular architecture can be applied to support a product's disassembly, serviceability, and adaptability. Third, functional and structural characteristics can be specified to allow the application of recovered resources, like recycled materials or refurbished components. Fourth, product features can be standardised to increase the relevance of recovered resources by creating compatibility between different systems. The challenge is to implement this design strategy and the four included approaches in industry practice.

3. Industry application

To research how the strategy of resource circulation can be practically implemented, an industry case is adopted. This particular case regards the corporate context of Remeha and focuses at the development of domestic boilers.

3.1. Industry case

Remeha, a business unit of the BDR Thermea group, specialises in the development of 'gas-burning condensing combined boilers' for industrial and domestic application, as mentioned in [12]. Their boilers are engineered and assembled at the facility in the Netherlands where over 550 employees contributed to the manufacturing of about 240,000 boilers in 2017. Part production is outsourced to suppliers. Over the past 80 years, Remeha has grown to become one of Europe's largest manufacturers of heating systems and an extensive network of service channels distributes products to national and international markets.

In pursuing the circular economy, Remeha prefers to apply measures that support a structural application aligned with the fundamental concept of circularity. Additionally, the solution should be directly applicable to the current development of domestic boilers while attaining relevance for long-term developments as projected by Remeha. This motivates the selection of the resource circulation strategy in section 2.4.

3.1.1. Characteristics of a domestic boiler

Remeha develops and services its domestic boilers for a lifespan of 15 years. The core technology for high-efficiency energy conversion is matured and the product's value for the customer is in its functionality, limiting the sensitivity to aesthetics or trends. Boilers are developed with a predominant focus on performance in the use phase with regard for maintenance and repair activities. The end-of-life processes that succeed the use phase are not yet actively considered or promoted in development [12].

3.1.2. Target group product engineers

Product engineers are responsible for developing technically feasible solutions in response to market demands. They define product characteristics, like functions and materials, thereby influencing resource circulation. Remeha's product engineers ground their decisions mainly in considerations of quality, reliability, costs, manufacturability, and serviceability. Most engineers have occasionally encountered considerations of sustainability in current or previous work environments, but there is no established experience with or knowledge of developing domestic boilers for a circular economy.

3.2. Identifying the need for support

As a result of the adopted design strategy as described in section 2.4, end-of-life considerations now become a priority in development. To successfully act on these considerations, product engineers require knowledge on the relation between domestic boiler characteristics and the reverse cycle processes from table 2. Therefore, a design support tool has been developed for Remeha to support product engineers in developing domestic boilers for resource circulation.

3.2.1. Design requirements

The following design requirements were formulated to direct the development of the design support tool:

- Provide engineers with relevant information on the relation between boiler characteristics and reverse cycle processes;
- Align with expertise and experience of the target group;
- Allow adaptation to an evolving level of expertise;
- Align with established development process and workflow;
- Provide individual and easy access to support

3.2.2. Solution principle

The solution principle is introduced in this section as one particular approach to addressing the design requirements.

[1] End-of-life scenarios should not only be considered for the product as a whole, but for its enclosed modules, components, and materials as well.

The backbone for support consists of a coherent set of design guidelines to inform and inspire product engineers in their daily engineering activities. Guidelines are customised to fit the product engineer's influence and level of expertise with developing boilers for resource circulation. The guidelines are embodied by a web-based tool that structures the guidelines into product-specific categories, elaborates each guideline's rationale, and supports their application with case-specific illustrations. The tool should be applied to the ideation and conceptualisation of technical solutions in the early phases of the development process, when design decisions still have a considerable impact on the product's sustainable performance [13]. Verification with the target group confirms that they are familiar with the use of design guidelines. Product engineers acknowledge the value of representing guidelines in a digital interface and regard the proposed categorisation as useful.

3.3. Guidelines

Guidelines can offer prescriptive recommendations for design decisions to guide actions towards a desirable result [14]. To formulate substantiated guidelines, an information base was established from literature. Some studies report on product development for a circular economy [15] and multiple publications were found on more particular fields, such as design for (dis)assembly [16], recyclability [17], modularity [17], and remanufacturing [18]. This was supplemented with insights from experts on recycling and refurbishment, resulting in an inventory of guidelines on development for resource circulation. Based on evaluation with the target group, guidelines from literature were found to:

- articulate high-level aspirations that are not actionable for product engineers;
- impose restrictions by specifying what should *not* be done;
- be described with complex or ambiguous terminology.

In response to these findings, the guidelines were adjusted according to three criteria from Telenko et al. [17].

- Actionable: guidelines propose practical directions for design activity to improve products;
- Positive expression: guidelines stimulate a positive approach to problem-solving, aiming at opportunities;
- User-oriented: guidelines apply to the interpretation and influence of the Remeha's product engineers.

connection 01

Specify connections that can be detached and re-attached, repetitively

Easy assembly and disassembly of components increases the effectiveness of reverse cycle processes. Ensure options for re-attachment in accordance with continued product lifecycles. Prioritise (economically) valuable components that are fit for reuse or refurbishment.

con 01.1 Use mechanical fasteners rather than adhesives

con 01.2 Prefer separable snap-fit joints for plastic components

Fig. 1. Example design guideline, based on [17, 19].

Applying these criteria to reformulating the guideline inventory has resulted in a custom set of guidelines that aligns with the target group. A guideline example is shown in Fig. 1.

3.4. Design support tool

Apart from the information that the guidelines provide, the shape in which they are presented to the user, influences their application. Following the solution principle, a digital user interface presents the guidelines in an orderly way. For easy access and reference purposes the guidelines were categorised based on the different levels of product definition: architecture, component, connection, and material. Each category represents an aspect of the used product definition: the overall product architecture is built from components that are fixed by connections and constructed from materials. By linking the guidelines to this product definition, they implicitly relate to the development decisions at different levels of detail.

Furthermore, each guideline is supported with a specific explanation that clarifies its underlying rationale. These explanations are meant to increase understanding in support of applying a guideline and to provide a basis for making trade-off decisions in product development. To explain how these guidelines might be applied in practice, some are illustrated with design solutions, often from existing boiler designs.

The proposed guidelines are meant to be used as a source of information and inspiration and not as a fixed set of rules to be obeyed. It is up to the engineer to decide what guidelines to apply, depending on the design case scope and constraints.

The structure of the tool, categorizing guidelines related to product definitions, clarifying the rationale and illustrations is visualised in Fig. 2. A public version of the tool is available via the following URL: https://home.et.utwente.nl/designtool. The access code to view the tool is: LCE2018.

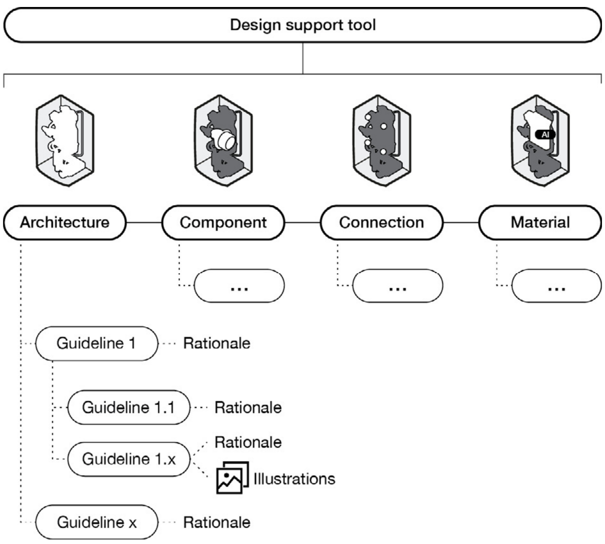

Fig. 2. Design support tool information structure.

3.4.1. Tool implementation

A successful implementation of the design support tool in product development should address both the management and the operational levels in an organisation [20]. Company management was involved in the decision-making process that defined the tool's principle solution (section 3.3.2) and underlying strategic direction (section 2.4). Resulting in management's endorsement, culminated in the incorporation of concrete process deliverables for Remeha's product development process. Additionally, involving the target group in defining the tool's structure and contents has established a general willingness to use the design support tool in their daily activities, as will be further explained in section 3.5.

3.4.2. Scalability and maintenance

The information content of the design support tool has been customised for the product engineer's current knowledge and experience with developing products for a circular economy. As Remeha's product engineers become more experienced with applying the strategy of reverse cycles, their need for related design support is expected to change towards more in-depth know-how. And the need for a broader area of support might arise in response to the adoption of additional design strategies for the circular economy. Moreover, regular use of the tool is likely to lead to new insights that can supplement its content. Therefore, the tool should be updated regularly to align the development of the tool with the development of the product engineers.

In the tool's current state, changes to its content are limited to: guidelines and explanations, examples, and informative resources. These adjustments are technically possible and allow the tool to flexibly adjust to changing user needs.

3.5. Usability test

A usability test was performed with nine participants from the target group to verify the usability of the tool's interface and the applicability of its design guidelines in the development of domestic boilers. The test setup consisted of three distinct phases; introduction and design case in a group setting, followed by an individual questionnaire. By means of a presentation, participants were first introduced to the concept of the circular economy and the relating purpose and scope of the design support tool, without explaining the interface. This was followed by a 45-minute design case where the participants applied the guidelines from the design support tool to develop a conceptual redesign of a boiler component. The design case simulated a probable use scenario and allowed participants not just to review the information presented in the tool, but to actually apply the information for generating design solutions. After completing the design case, each participant individually rated 11 statements on a 5-point Likert scale.

Qualitative data was collected through direct interaction with participants, observation and a questionnaire. Participants unanimously agreed or strongly agreed that the guidelines are clearly formulated, are applicable to their design case, and can be used for their regular engineering tasks. Likewise, participants all agreed or strongly agreed that the tool is pleasant to work with, provides easy access to information, and provides useful insights on how to develop products for a circular economy. The usefulness of the examples and explanations that accompany the guidelines is generally agreed on. All participants indicated to be willing to use the tool for their development projects. Some supported this statement with a remark on the usefulness of the tool and the positive energy it provides.

Evaluating the test results, it can be stated that the tool can be intuitively used by the product engineers, without prior training or experience with the tool or with circular product development in general. Product engineers found the tool's content to be accessible and the use experience to be pleasant. Users have demonstrated a considerable understanding of the guidelines and underlying philosophy, inspired by the tool but also credited to the abilities of the product engineer. This is reflected by lively discussions during the design case and the concrete design proposals that resulted from the design case. Based on these results and expressed opinions of the product engineers, it can be concluded that the guidelines provide useful insights that are applicable to the development of domestic boilers. This way, the design support tool has been verified as an accessible and practical solution that is accepted by the users and leads to new and concrete design proposals for domestic boiler components.

4. Conclusion

From the described evaluation can be concluded that the tool is accepted by the product engineers and supports them with relevant recommendations. The applicability and usability of the tool were enhanced by categorising guidelines into product-related groups. Explaining the underlying rationale of guidelines together with case-specific examples of their application further increased the knowledge base of the product engineers.

Deliberately selecting a specific design strategy, like develop for resource circulation, concentrated the development of the case-specific guidelines and their implementation by the tool. Moreover, the process of defining the scope of implementation in terms of specific design strategies in section 2 has proven to be meaningful for higher management to direct and support development efforts for the circular economy.

In this research, it became apparent that the characterisation of the circular economy in terms of the five principles, as described in section 1, enabled constructive and consistent discussions about the context of implementation in practice. While the principles remain too abstract for most stakeholders, the general understanding that circular economy should be considered as one approach for achieving sustainability appeared to be useful for company management.

In response to the problem statement, a structured process was adopted in this research to implement abstract principles of the circular economy in a case-specific product development environment. Summarised, this process contains the following generally applicable steps:

- Establish the position of the circular economy as an approach to sustainable development;
- Characterise the circular economy in terms of principles;
- Specify the focus for implementation in relation to the company structure of departments;
- In the domain of product development, identify relevant strategic directions for translating the principles of circularity into the application domain;
- Determine which strategic direction to implement and determine the necessary means of support;

If a dedicated means of support needs to be developed, consider the following elements:

- Identify the appropriate target group and their responsibilities, skills, and workflow;
- Specify the target group's needs and preferences for support and formulate development requirements accordingly;
- Develop the required support through an iterative process in collaboration with the target group;

Finally, it can be concluded that the developed tool actually supported the product engineers in developing domestic boilers for resource circulation, while increasing knowledge of the company about the circular economy.

5. Discussion

Although the developed design support tool was well received by the target group, there is no proof yet of how the tool actually effects the development of future domestic boilers. Additionally, it remains unknown how those new boilers actually fit reverse cycle processes and impact resource effectivity in a circular economy. Further research would be needed to evaluate the effect of the design support tool. While the tool focusses on the domain of product development, alignment with supply chain and business model is required to reach the full potential of the circular economy. Research on the interaction between these three domains and their concurrent development would be valuable for further implementation of the principles of circular economy in industry. Resulting insights could be used to expand the proposed process for implementing principles of circular economy to include not just product development but also the domains of supply chain and business model.

The approach of developing a design support tool for a specific industry case, as summarised in the conclusions, is expected to be applicable to similar industry cases. An experienced product development department for familiar and matured technical products would be a requirement. However, if there is already a lot of experiences with, and knowledge about sustainable design and the principles of the circular economy, the presented solution might prove less effective.

Furthermore, it is expected that the evolving knowledge and experience of the product engineers by applying this design support tool can be transferred to the development of future generation of heating products that will arise from the impact of a transition towards renewable energy sources.

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