Applying tools for end of use outlook in design for recirculation

Citation for the original published paper (version of record):

Hildenbrand, J., Lindahl, E., Shabazi, S. et al (2021). Applying tools for end of use outlook in design for recirculation. Procedia CIRP, 100: 85-90. http://dx.doi.org/10.1016/j.procir.2021.05.014

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 100 (2021) 85–90

www.elsevier.com/locate/procedia

31st CIRP Design Conference 2021 (CIRP Design 2021)

Applying tools for end of use outlook in design for recirculation

Jutta Hildenbrand[a], Emma Lindahl[b], Sasha Shahbazi[a], Martin Kurdve[a,c,]*

[a]*RISE – Research Institutes of Sweden, Göteborg, Sweden*
[b]*KTH Royal Institute of Technology, Dept. Sustainable Production Development, Södertälje, Sweden*
[c]*Chalmers University of Technology, Technology management and economics, Supply and operations management. Göteborg, Sweden*

* Corresponding author. Tel.: +46 -31-7721000; *E-mail address:* martin.kurdve@chalmers.se

Abstract

Circular economy is widely embraced as one major path towards sustainability goals by contributing to resource efficiency and reaching climate targets. The research need at hand lies in how to implement changes. To achieve a circular system, design for recirculation is advised when introducing new products and production processes. However, in practical applications it is a challenge to foresee the complex nature of a real circular production system with many stakeholders in a system in transition. Product systems are embedded in a use context, where the user is a key stakeholder. Collection and systematization of experience and ideas from the field is here a key. This research draws on the experiences of assessing and improve circulation in industrial practice deploying the Recirculation Strategies Decision Tree and the Eco-design-strategy-wheel. Through two case studies, practitioners have been supported in action to evaluate their products and production processes in term of circularity. Cases showed a process from current status and recirculation challenges to a more circular future state in production and end of life was scrutinized. As a result, emphasis differed between the two tools. The Eco strategy wheel supported product design phase with an engineering perspective, The Recirculation Strategies Decision Tree on end-of-life phase with a market perspective. Common for both tools was the dependency on user or operator's handling. Outcome from this study is to emphasise the importance on social dimension in CE/user role in a circular product system. The interactive, user centered research with manufacturing companies is suggested for development to effectively close product loops.

Keywords: Circular economy; resource efficiency; design for recirculation; end of use; interactive research;

1. Introduction

Circular economy is widely embraced as one major path towards sustainability goals by contributing to resource efficiency and reaching climate targets. The research need at hand lies now more in how to implement changes than in analyzing which changes are needed and prioritized. Therefore, tools and methods that provide reasonable and correct directions in a time efficient manner are crucial.
In the past literature, several green design tools have been introduced [1, 2]. However, several tools presented by research merely analyse a static system, while fewer support the transition process.

To achieve a circular product system, design for recirculation is advised when introducing new products and production processes [3]. However, practical applications are often simplified and rarely give the complex nature of real circular systems in transition with many stakeholders. User needs develop over time as well as the offerings, and the initial intention of the design might not be suitable, thus requiring changes that are negative for recirculation. Analysing the status of products that have reached the end of a use phase and are no longer needed by a specific user, is necessary to decide further actions to recover value. Collection and systematization of experience and ideas from the field is here a key.

In this research, two circulation-related tools applicable for SMEs according to research [1] were used. In addition, the process of deploying the tools were also analysed in order to

10.1016/j.procir.2021.05.014

understand which features of the tools and the process of using them that are useful in the design for circularity practice.

The objective of this paper is to help practitioners and scholars to understand the different features of each tool in term of practicality and usefulness. To fulfil the research objective, two main research questions were proposed: (1) what success factors are seen when deploying a circulation-related tool in production? (2) how can the tools be used in (re-)design phase of next generation of a product?

2. Theoretical context

Human Centred Design (HCD) takes user experiences behaviour, and learning into consideration [4]. The design thus requires systematic feedback of user experiences and learnings. Product systems are embedded in a use context, including competitors' offerings. With changes of the product system, users norms and beliefs evolve, which is why the user feedback needs to change, possibly using HCD [4].

In lean company settings, a preferred method for re-evaluation is through kaizen [5] , or continuous improvements, used to improve both operation procedures and physical artefacts. From a current state kaizen does step-wise improvements towards a target state, while experimenting and learning [5]. The development in eco-design or green design include holistic systems thinking in a breadth of areas, physical design, 'service content' and user experience etc., which is in line with the view of 'good design' as a rational activity that results in sensible products [6]. In eco-design, the availability of information limits the design knowledge in early stages.

Circular Economy (CE) offers resource efficient solutions to sustain within the planetary boundaries while achieving economic growth [7]. CE-thinking has been introduced as a path towards more sustainable solutions, in product and business development [8]. In its largest scope, CE may involve energy and material circulation, the prolonging of materials, components and products' lifespan and some literature includes social and economic sustainability [7]. CE recirculate and minimise resource flows by closing, narrowing and slowing speed of the flows achieved by design for longevity, maintenance, repair, reuse, remanufacturing, refurbishing and recycling, as defined by Macarthur [8]. In practice, use-phase experiences are rarely addressed even in CE-design tools like LCA [9]. Practical CE-solutions involve e.g. circular product design, closing the loop for post-consumer waste, new business models and industrial ecosystem perspectives [10]. The solutions can be grouped into prolonging life (design for longevity and maintenance) and circulation (i.e. reuse, remanufacture refurbishing and recycling) [11]. A potential CE-toolbox could also include tools for redesign of: ownership, maintenance services, localisation, and business models [12]. Companies can analyse what their value-chain role means for implementing a wide range of CE-retention options [13].

2.1 Recirculation Strategies Decision Tree (RSDT)[3]

Linear product life cycles depend on the availability of resources from start to finish. Resources are extracted, transformed to materials, components and products, then they are used for a limited time and eventually disposed with a product. This means a great loss in all value created throughout the forward supply chain. CE fosters the recognition that the linear economic model is unsustainable and need to be re-designed. Solutions are needed for existing market products, that are currently being used, and which are approaching a stage when they are not fully functional for a specific user, either temporarily or permanently. Unfortunately, many existing products were mainly designed and manufactured without sufficiently considering circulation of materials and products of any sort, or the intended recirculation is no longer feasible since users made changes that were not foreseen.

Recirculation Strategies Decision Tree [3] (figure 1) has been developed to identify and redesign the and-of use and end-of-life fate of products. Extending the products' lifecycle and closing the loops can start by recirculating strategies for products or parts as the primary option, and secondly recirculating strategies for materials, as the last resort. Therefore, nine different recirculation strategies can be defined and investigated in order to:

Recirculate products and parts through extension of existing use-cycles (end-of-use)

1. Upgrade
2. Repair and maintenance

Recirculate products and parts through extension to new use-cycles

3. Reuse
4. Refurbish
5. Remanufacture
6. Repurpose

Recirculate materials: effective application at end-of-life

7. Recycle
8. Cascade
9. Recover

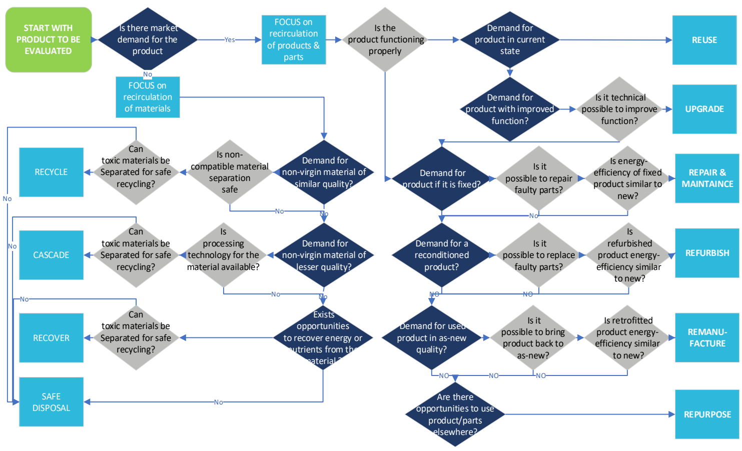

Fig. 1. Recirculation strategies decision tree [3]

The value preservation and recapture from existing products is higher in the first strategy (upgrade) and it lowers moving towards the ninth strategy (recover). Remanufactured products can have equally high value for a subsequent use-cycle, this is however created through an intervention. Hence, the top strategies are always preferred and should be prioritized.

2.2 Eco strategy wheel (ESW)

Eco-design aims at improving environmental performance via integrating environmental considerations throughout the product and process development stages [14]. Life cycle assessment (LCA) data from existing products and processes are ideally used as a feed-back to design [15], however the needed data are not usually available and, consequently must be estimated based on similar products, or simplified. Sometimes, screening type LCA based on limited information is used instead of detailed assessment of environmental impacts of the product or processes.

The Eco strategy wheel [16] has been developed with an aim to support eco-design throughout all design stages including product design, production, use and end-of-life phases. This tool can be used as a base for continuous improvements and as complement and template for data collection for LCA. The eco strategy wheel (Fig. 2) can be a time efficient, easy to use, qualitative tool, substituting a full and/or proper LCA in early phases of design where data is not available. The eco-design strategy wheel is reconfigured from an approach originally proposed by Brezet for UNEP [17, 18] and address all life cycle stages in order of significance and information ability. Accordingly, the most important issue is: (1) to assure functionality of the product and process, (2) to minimise environmental impacts during the use phase, (3) to minimize the amount of resources, (4) to select the right materials, (5) to optimize lifespan, (6) to optimise production, (7) to optimize end of life, and (8) to optimize distribution. This tool can be used for products, services and processes.

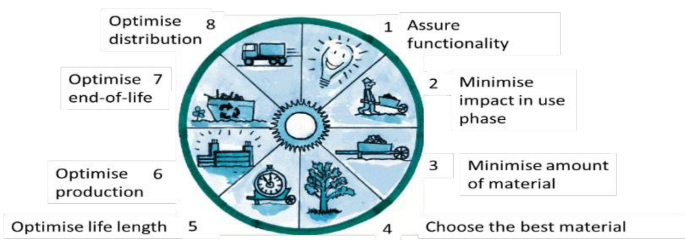

Fig. 2. Eco-design strategy wheel [16] adapted from [18].

3. Materials and methods

This research follows a case study approach strengthened by interactive research with manufacturing companies located in Nordic countries through several previous and ongoing projects. Through several collaborative empirical studies and workshops within those projects, manufacturing companies and practitioners have been supported to evaluate their products and production processes in term of circularity and sustainability. In addition, the evolution process from current status and recirculation challenges to a more circular future state in production and end of life was scrutinized.

This paper is an extension of mainly three Swedish research projects supporting manufacturing industry with tools underpinning circularity and sustainable development. This research's foundation is based on empirical experiences of assessing and improving sustainability and circulation in industrial practices deploying Recirculation Strategies Decision Tree (RSDT) and Eco strategy wheel (ESW), among other tools. However, this paper only reports on application of these two tools only. The tools were chosen among numerous tools using criteria stipulated by professionals in the project and e.g. Lindahl and Ekermann [1], easy to use, quick to deploy and applicable early in the design process. The difference is that ESW aims at a holistic eco-design approach based on the information available at the time of design, while RSDT aims at supporting activities at the end-of-use and end-of-life phase only, but considers interaction with users and their changed needs. From a methodological point of view in addition of the RQs it is of interest to see how this difference would impact the result and the process.

The tools were applied on two manufacturing companies with totally different products. Company A produces multiple use protective packaging (mainly for manufacturing industry) made of single material (foam) with relative short lifespan while company B produces house modules made of multiple materials for temporary and permanent applications, thus with relatively long lifespan. Both companies were small or medium sized enterprises (SME's) and had been collaborating with academia for some time.

Company A's product was studied in 2019, while they developed a packaging concept for protecting automotive parts during transport to assembly. This study was followed up and complemented with research interview in 2020. Company A started almost thirty years ago and has around 15 employees. The main data collection for this case is direct observation of production and use of the product and a semi-structured interview with the chief of marketing.

Company B's product was studied twice, first in winter 2018 then after some redesign again in 2020 with observations and a semi structured interview with the CEO/owner. Company B started 4 years ago and has 3 employees and the owner. Research studies of company B has been ongoing since 2016 involving, first, business model innovation [19] where a design driven innovation strategy was suggested for social and environmental sustainability, and secondly, environmental sustainability for the prototype house module design [14].

This paper has its main foundation on empirical studies and interactive collaboration with companies. However, the theoretical studied has been used primarily to describe requirements on design for recirculation and green tools for eco-design.

4. Results and analysis

4.1. Foam packaging case A

The Foam packaging was assessed through the ESW starting with *assure functionality* (nr.1) of the foam packaging material, protecting mainly components from the automotive industry that are transported from a supplier to assembly. The packaging is folded for transport back to the supplier, thus the payload for return *transport is optimized* (nr 8). The main function of the product is to minimizes defect of products (automotive parts) during transportation. The foam material is light and easy to form. The performance is high and still with thin material. The *impact in use phase* is low, no hazardous material is emitted or

ESW	A	B
1. Assure functionality	Protecting goods efficiently	Easy to assemble house modules
2. Minimise use-phase impact	Low, no emissions	Energy efficient construction, no hazardous emissions
3. Minimise material waste	Optimized cutting, customized for client	Standardized design eliminates production waste
4. Choose the right materials	Renewable plastic materials, processed recycled	Plastic moisture barrier was removed
5. Optimise product life	Durable for several user cycles	Long life time, parts to be exchanged or upgraded after some years
6. Optimise production	Methane used in production, process recycling solely same material	High social concern in production, easy-to-use tools and assembly instructions
7. Optimise E-O-L	Dependent on user handling in collection and sorting	Remanufacturing alternatives for damaged parts. Degradation to simplified function, shed etc.
8. Optimise distribution	Light weight material, easy mobility, storage	Modules are tightly packed on distribution trucks

harmful for the operator environment (nr.2) The purpose is to fill pallets as effective as possible with goods. The design of the foam is optimized to leftover space and *minimize material use* (nr.3). The foam consists of a single renewable plastic polyethylene (PE), including some recycled PE (nr.4). The foam is durable for several use cycles (nr.5). The handling is critical for the designed performance. The production of the foam uses methane gas as a process material and the material source is a mix of renewable fossil PE and recycled PE (nr.6). Broken products can be recycled in closed loop recycling into new PE-foam. Only the same PE-foam material can be taken into the closed loop foam recycling process. The end of life of the product is depending on the end user's handling. It has to be sorted correctly in order to be brought back to production (nr.7) but if it is mixed with other PE-packaging materials it can still be recycled in open-loop recycling into other plastic packaging products. The distribution is facilitated as it is a light material, easy to store and move. The take back distribution is aligned with the primary distribution (nr.8).

Assessment through RSDT showed the product is generally reusable at the end of a use cycle, but also that no other actor is interested in the product after life as it is customized for a certain protection. Therefore, the demand of (functioning) products for reuse and damaged but clean material for recycling is high, intended to be used by the same actor. The foam protection is not functioning properly when it is damaged, the product is then handled from a material recycling perspective. Remanufacturing or repair is not an alternative, any attempts to apply glue or similar substances during the use phase effectively prevent closed loop recycling and means that the product can be used in general polymer recycling together with post-consumer waste. The product preferably circulates in a closed system as the material is to as-good-as new quality after recycling. It also only come in contact with the manufacturer and recycler, the designer and the end-user. The foam is not intended for re-purpose as packing fillers, which are not seen as a sustainable product due to losses but can be used as input to produce air bubble film.

Table 1. ESW assessment on case A and B

4.2. House module case B

The ESW assessment started off from an ESW assessment of the prototype [14]. The house module *functionality* was the same compared to the prototype version of the product (nr.1). Modules are produced and assembled in a standardized way using easy-to-use tools. *In use*, the assembled house has a high energy efficiency performance and does not emit hazardous substances to the interior or the environment (nr.2). Modules are built using renewable, mainly biobased materials (nr.4) with material efficiency in mind (nr.3) and sufficient to stay durable for longer than expected lifetime of 15 year (nr.5). Plastic materials have been removed from the module design since the prototype. The moisture barrier, which was initially a fossil-based polymer is now replaced with a biobased material. All components in the module have a long life-length. After 15 year of use, roofing, windows, doors and the outside painting could be reviewed and upgraded or recirculated as parts (nr.5). Production is focused to include workers with diverse background and typically low education and training level without any housebuilding competence. As the assembling is standardized and easy to learn, the production process as social innovation is part of the business idea (nr.6) [19]. End-of-life cover several user stages of house module. Modules are able to be upgraded, and partly remanufactured if damaged. The function could also be degraded to use as a garage or a shed. Parts from modules could be taken back to production. The last step is material recycling of wooden and metal components, and possibly incineration (nr.7). Houses are effectively packed on delivering trucks, simulations have been done in order to optimize distribution (nr.8).

Table 2. Recirculation Strategy Design Tool (RSDT) assessment on cases A and B

RSDT	
A, Foam packaging	B, House module
Reuse and closed loop material recycling for same user as preferred option. Where returned products or material is not sufficiently clean, material recycling with other polymers to air bubble film is possible.	End-of-Use: Upgrade, repair and reuse (at new location) as preferred options. Modules can be used for refurbishment of damaged houses. End-of-life: Using modules for refurbishment, material recycling for insulation and repurpose for low demand level (shed, garage). Energy recovery from wood structure, material recovery for metals and glass.

According to RSDT, the application can be distinguished in two typical use patterns, as a temporary housing or as a permanent housing. For houses used for temporary housing, it can be assumed that they have not reached their end of servizable life when the temporary use phase ends after 10-15 years (the legal limit for temporary buildings in Sweden). In this case, the modules can be disassembled, tested and where suitable transported and assembled at a different location. Modules that are not damaged can be used as is, or upgraded, or repaired where needed to adapt to user needs. Damaged modules can be removed and used to repair and refurbish other houses or repurposed as shed or equal low-demand application. Houses that have reached an end-of-life after several use phases or after a single longer use phase can equally be disassembled, however the modules might be no longer suitable for reuse or upgrade In this case, using components such as doors or windows for repairing and refurbishing other houses as well as repurposing the structure for applications with lower demand, such as sheds or garages can still be an option depending on the state of the building and its components. Material recycling after disassembly is also an option, including energy recovery from the wood-based structure. Physical damage (holes) is usually limited to a single module. Based on the limited time the product is on the market, malodour from smoking indoors or burning food is a damage that prevents subsequent use, as this may be difficult to remove from the module material. In this case, energy recovery is the most valid recirculation.

4.3. Tool comparison

Both tools were used at both companies A and B, following the same structure and consistency. According to the results, there are some similarities between the tools with regards to how they address CE. However, they take a different viewpoint in how they tackle circularity of products. The ESW is mainly focused on product design phase with an engineering perspective, while the RSDT is mainly focused on end-of-use and end-of-life phase with a market perspective.

Product circularity is very much dependent on decisions made during product design and development phase, particularly early phases including concept development and system level design [20]. These decisions include product specifications such as form, function, feature, robust, environmental, ergonomic, geometry as well as product identity, functionality, usefulness and product image in the market. Selection of material is also an important part of early product design phases.

The ESW (see table 1) addresses recirculation within such decisions in form of optimizing functions (nr.1), reducing quantity of materials (nr.3), selection of (recirculated) materials (nr.4) and optimize product disposal (nr.7). Optimizing function (nr.1) addresses sell function instead of product, where designing a product for durability and robustness plays an important role. Reducing quantity of materials (nr.3) is an essential rule in recirculation of materials in form or design for recycling and cascade, where the number of different incompatible or dissimilar materials should be minimized to facilitate shredding and using the same recycling method/processes without any separation. Selection of materials (nr.4) addresses designing a product using renewable, recyclable and environmentally friendly materials. Materials should be also preferably sourced from secondary resources i.e. being recycled. Optimize product disposal (nr.7) addresses striving for higher value recirculation strategies i.e. enabling upgradability and repairability as first priority and then remanufacturability. If none of recirculation strategies for products and parts through extension of existing use-cycles or extension to new use-cycles works, then aim to recirculate materials via recycling and cascading.

RSDT systematically analyses products at the end of use or end of life and assumes that recirculation strategies aim to reclaim as much as possible of the initial value to subsequent use cycles and life cycles, where needed also by adding and replacing components or other large scale interventions. Activities that are foreseen to support recirculation in the design phase can still have options that cannot be completely implemented due to user behavior. Thus, the return of a product is an opportunity to reconnect and reassess options and adapt where needed. Both cases described here offer a multitude of options compared to conventionally designed products; single use protective packaging means material recycling is the only option, and due to perceived low value of packaging the return rate is low. A tailormade returnable packaging thus offers reuse and increases the participation in recycling activities. The modular housing offers flexibility and thus increases options for the construction sector. Regular houses can be used by several tenants or owners in a sequence, and remodeling to adapt to user needs regarding size and layout is also possible. However conventional buildings are supposed to last and require a long time to build, and options to use space that is available for a limited time or offer housing for a limited time during renovation or construction of new buildings are limited.

Addressing *optimize product disposal* to consider end-of-life of product, components and materials is the main overlap between the two tools. Lessons from RSDT can be used for future designs to refine the ESW. RSDT hugely benefits from the application of ESW during design, as options for recirculation are facilitated through material choice and consideration of disassembly.

ESW allows the design of an optimised circular product system, however it does not specify in detail how it should be arranged. RSDT gives circular flow options in the model, and shop floor need to support the circulation criteria. From company examples, it is seen that the human involvement is crucial in closing loops. Key roles in closing loops are users. In a manufacturing situation the user can be translated to the operators, who need training in adjusting behaviour from linear flows of packaging (single) use to circular (multiple) use of packaging in case A. In case B, the production and remanufacturing is centred by the human skill and ability in the combined assembly, inspection of returning module and reassembly.

5. Discussion

The application of ESW in most parts confirmed Lindahl and Ekermann [1], it was fast to use and easy to use. The tool also supported design of the end-of-life stage of both products. The application of RSTD as a complementary tool in part is hampered by the multitude of terms and definitions established in different industry sectors; practitioners need more guidance and explanation using it. While the different and preferable options could be identified for both cases. Some of the end-of-use strategies and the differences between them are not well established in practice and need to be further investigated for different types of products to identify priorities. Lessons learnt while applying the RSDT can be used to further enrich and refine the ESW during a subsequent loop.

Both cases link to the study by Lofthouse and Prendeville [4] and learnings could be used to train personnel in gradual improvements of closing material loops and integration in the kaizen [5]. Holistic view on material circularity, social dimensions, adding on the circular economy concept by Tukker [12] issues like service, ownership put the human-centred focus in a circular product system on the map. As result, a path forward for how academics, practitioners and consultants can collaborate to collect necessary information and knowledge in designing circular products and production processes could be developed. Such framework would help practitioners in transition towards a circular economy and industrial sustainability.

6. Conclusion

Previous studies have shown that there is an insufficient use of practical tools and methods for end of use design for recirculation. Consequently, there is also few practical tools to support circular economy practices in operations. Therefore, in this paper, two green tools used in two manufacturing companies and on two different products. These tools are eco strategy wheel and recirculation strategies decision tree (Fig. 1 and 2). These tools have been deployed in several research projects, but for this paper, they are compared to one another in order to understand the different features of each tool in term of practicality and usefulness.

The results show how various tools are highlighting different stages in the circular product system. It indicates that a combination of green design tools could be used and combined for different types of situations and use-cases, to assess various environmental impacts, get better decision-making and increase the awareness of the recirculation performance and the value of the product.

Acknowledgements

The research work is part of the Nordic research project CIRCit (Circular Economy Integration in the Nordic Industry for Enhanced Sustainability and Competitiveness), financed by NordForsk, Nordisk Energy Research, and Nordic Innovation, and the project Leda Grönt, financed by Vinnova, the Swedish Innovation agency. The study partly builds on result from CiMMRec, financed by MISTRA. The authors gratefully acknowledge the contributions from all the industrial and academic participants in the CIRCit and CiMMRec. All authors contributed equally in this paper.

References

[1] M. Lindahl, S. Ekermann, Structure for categorization of ecodesign methods and tools, in: N. A., S. B., O. SK. (Eds.) Re-engineering manufacturing for sustainability, Springer, Singapore, 2013, pp. 117-122.
[2] G. Johansson, E. Sundin, Lean and green product development: Two sides of the same coin?, Journal of Cleaner Production, 85 (2014) 104-121.
[3] J. Hildenbrand, S. Shahbazi, J. Dahlström, T.H. Jensen, D. Pigosso, T. McAloone, Closing the Loop for a Circular Economy: CIRCit Workbook 5, 1st ed., Technical University of Denmark, Copenhagen, Denmark, 2020.
[4] V. Lofthouse, S. Prendeville, Human-Centred Design of Products And Services for the Circular Economy – A Review, The Design Journal, 21 (2018) 451-476.
[5] M. Rother, Toyota Kata: Managing People for Improvement, Adaptiveness and Superior Results, McGrawHill Professional Publishing, 2010.
[6] J. Heskett, Design: en introduktion, Raster Förlag, 2006.
[7] J. Kirchherr, D. Reike, M. Hekkert, Conceptualizing the circular economy: An analysis of 114 definitions, Resources, Conservation and Recycling, 127 (2017) 221-232.
[8] E. Macarthur, Circularity indicators: An Approach to Measuring Circularity., in: E.M. Foundation (Ed.), 2015.
[9] J. Daae, C. Boks, Opportunities and challenges for addressing variations in the use phase with LCA and Design for Sustainable Behaviour, International Journal of Sustainable Engineering, 8 (2015) 148-162.
[10] J. Konietzko, N. Bocken, E.J. Hultink, A Tool to Analyze, Ideate and Develop Circular Innovation Ecosystems, Sustainability, 12 (2020) 417.
[11] M. Lindahl, Key issues when designing solutions for a Circular Economy, in: M. Charter (Ed.) Designing for the Circular Economy, 2018.
[12] A. Tukker, Product services for a resource-efficient and circular economy – a review, Journal of Cleaner Production, 97 (2015) 76-91.
[13] D. Reike, W.J.V. Vermeulen, S. Witjes, The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options, Resources, Conservation and Recycling, (2018).
[14] M. Kurdve, J. Hildenbrand, C. Jönsson, Design for green lean building module production-Case study, Procedia Manufacturing, 25 (2018) 594-601.
[15] L. Lindkvist, E. Sundin, Life-Cycle Information Feedback to Product Design, in: Proceedings of the 5th International Swedish Production Symposium, SPS 12, 6-8 November 2012, Linköping, Sweden, Produktionsakad., The Swedish Production Acad, 2012, pp. 99-105.
[16] A.K. Jönbrink, H.L. Norrblom, M. Zackrisson, Ekodesign praktisk vägledning, Swerea IVF, Sweden, 2011.
[17] V. Chulvi, R. Vidal, Usefulness of evolution lines in eco-design, Procedia Engineering, 9 (2011) 135-144.
[18] C. Van Hemel, J. Cramer, Barriers and stimuli for ecodesign in SMEs, Journal of Cleaner Production, 10 (2002) 439-453.
[19] M. Kurdve, H. de Goey, Can Social Sustainability Values be Incorporated in a Product Service System for Temporary Public Building Modules?, Procedia CIRP, 64 (2017) 193-198.
[20] K.T. Ulrich, S.D. Eppinger, Product design and development, in, McGraw-Hill/Irwin, NY, 2012.
[21] L. Olsson, S. Fallahi, M. Schnurr, D. Diener, P. van Loon, Circular Business Models for Extended EV Battery Life, Batteries, 4 (2018) 57.