DOI: 10.57649/GFC.978-989-54263
ISBN: 978-989-54263-3-1

Sustainable Design Decisions for Circularity – a Challenge

Françoise Adler [1]*, Lea Schmidt [1] Andrea Weber Marin[1] and Benjamin Willi [1]

Abstract
Considerable importance and responsibility are attached to the issue of design in the shift towards circularity. Environmental implications throughout the product life cycle must be anticipated in the design phase in order to enable the products to have second and third lives. A large number of theoretical concepts and 'design for X' action instructions for sustainable product development have emerged in recent years. The implementation of the theoretical approaches in design practice would be an important step towards promoting circular practices. There is a large gap here. The objective of this paper is to contribute towards closing the gap between theory and design practice by analysing, contextualising and translating the existing theoretical action instructions for low-threshold use in design practice, with a focus on the design of textile products. An initial graphical visualisation of the findings for design practice, a 'design decision tree', subsumes the findings from the literature search and analysis in a new, product-centric form. This overview can be used to determine which decisions can be taken when and by whom in order to promote product circularity. Detailed and networked action instructions enable designers to utilise their creative freedom in the interests of sustainability in practice, in line with science-based concepts and criteria. In the next step, the first version of the design decision tree will be tested using practical case studies from industry.

[1] Lucerne University of Applied Sciences and Arts, Switzerland
* Correspondence: francoise.adler@hslu.ch

Published November, 2023

Introduction

On the one hand, textile design research has gone far beyond traditional linear design strategies. It focuses on circular systems that aim to reduce virgin material consumption, eliminate waste and decouple growth from material use (Ghisellini et al., 2016). On the other hand, the design practice in the industry continues to orient itself along its established linear value chains, even after 11 years since Kirsi Niinimäki's call for a new sustainable mindset (Niinimäki and Hassi, 2011). That the goals mentioned above of a circular economic system have not yet been sustainably implemented in the industry can be deduced from recent figures: primary fibre consumption has doubled in the last two decades (Hickel, 2021) and continues to rise steadily (Textile Exchange, 2021) and textile consumption has increased by 40% since the mid-1990s (Šajn, 2019).

There are numerous approaches in design research concerning sustainability in product design. They have grown organically since the 1970s and are subsumed under the term 'design for environmental methods' (Stebbing & Tischner, 2015). They range from cradle-to-cradle (McDonough & Braungart, 2010), focusing on circularity at a material level while coining the term 'effectiveness in design' over eco-design strategies, including checklists (Stebbing & Tischner, 2015), to design for circularity (Ellen MacArthur, 2017), to mention only a few. Other approaches to diving deeper into the design for circularity include the concept of cascading (Campbell-Johnston et al., 2020). This concept presupposes design for longevity, recyclability and modularity (Bakker et al., 2014). The cascading necessity in the four value creation loops, re-use, re-furbish, re-manufacture and re-cycle, is best illustrated in the butterfly model of the EMA Foundation (Ellen MacArthur Foundation, 2013). Design for fast and slow cycles (Goldsworthy et al., 2019) is a recent design concept which reveals an essential perspective for fashion and textiles.

These are valuable approaches for a sustainable design perspective in textiles because they apply to the industrial textile product, its use until the end of its life and its supply chain. However, how these different approaches relate to each other and practically lead to sustainable design decisions during a design process is not self-explanatory and remains mainly elusive to design practice. At a meta-level, all of these approaches have the potential to change the industry. However, there is a gap between design research and design practice (Niinimäki and others, 2018) with regard to the implementation of such strategies, as they are not very tangible and lack translation into everyday design practice.

The European Union states in its product policy that the design phase influences more than 80% of all product-related environmental costs (European Commission, 2018). For design practice to influence that 80% product-related impact, explicit knowledge of the material, resource and manufacturing processes and their use and re-cycling is required. In addition, the aforementioned areas are interdependent regarding product-related environmental impacts, which the designer must consider in the design phase.

The fact that the above-mentioned sustainable design strategies stemming from design research have not yet led to a change from linear to circular systems in industry is consistent with observations from applied design research. Adler et al. argue that changing from a linear to a circular textile value chain is not straightforward. Every process within the textile value chain needs to be renewed and adapted towards circularity. Therefore, the necessary changes are not automatically connectable with subsequent processes (Adler et al., 2022). The complexity of the textile value chain is challenging, and the textile material and its different extraction, manufacturing and processing steps are numerous. These conditions make it difficult for design practice in fashion and textiles to steer design decisions that lead to improved product sustainability.

Regarding the initial situation and problem, the research work in this paper addresses the question: how can theoretical design strategies and concepts help to achieve greater product sustainability in design practice?

The aim is to make a concrete and scientifically verifiable contribution to closing the gap between design research and practice regarding improved textile product sustainability.

Method

The literature review identifies concepts containing action statements applicable to sustainable textile products. Because sustainability in textile products is a multi-perspective issue, the literature review contains three perspectives: 'design', 'ecology' and 'circularity'. The search terms were in English and German to cover as much theoretical ground as possible. The literature search ended after the first redundancies appeared.

Hits from the literature search were judged as relevant if concepts and their mentioned action instructions were applicable for textile products, in distinction, e.g. from pure business models. The researchers consecutively analysed the resulting concepts and action instructions in more detail.

These action instructions were systematically documented in an Excel chart to achieve an overview of existing concepts and action instructions from the analysed publications. Since the analysed publications stem from different disciplines, the researchers added partially supplemented descriptions derived from the publication.

To reduce the complexity of the collected action instructions and to establish references between these action instructions, clustering was performed from the design perspective. This research did not consider action instructions not relating to a product, e.g. 'design for effectiveness' (Shedroff, 2009). The chosen cluster terms helped to achieve an initial order and are not to be understood as a science-based assignment.

To increase relevance in terms of practicality, the researchers mapped the clustered action instructions according to 'product life thinking' (McAloone and Bey, 2009) along the different product life phases. Associated action instructions with similar meanings were re-labelled with summary terms following the literature.

Developing a graphical form improved the readability of the clustering and mapping. The graphical form allowed essential relationships between the action instructions and their relevance along the product life cycle to be presented.

Procedure/making of the design decision tool

The literature search in Google Scholar, ScienceDirect and Swisscovery was conducted for the 'design' perspective using the main keyword 'design' and variations of the terms 'sustainability', 'textile', 'recycling', 'recycled material', 'guidelines', 'strategies', 'methods', 'tools', 'usability' and 'slow'. For the ecological perspective, the main keyword was 'eco' and variations of the terms 'design', 'efficiency', 'design theory', 'design checklist', 'design methods' and 'design criteria'. For the circular perspective, the main keyword was 'circular' and variations of the terms 'textile', 'textile economy', 'textile product' and 'guidelines'. The search in German and English resulted in about 70 hits from different disciplines (design, economics, chemistry, architecture).

Book chapters, conference papers and papers were found. The researchers checked the 70 hits of the literature search for their applicability to sustainable textile product design. This review narrowed the 70 hits down to 16 publications from different scientific disciplines. From these 16 publications, 117 action statements were extracted and documented in an Excel spreadsheet ***(Tab. 1).***

The research group reflected on the action instructions from a qualitative perspective in workshops. The analysis of the 117 action instructions showed a) that different action instructions are named similarly but are not the same (such as 'design for recycling', 'design for closed loop', 'design with recyclable material input', 'design for recyclability', etc.) ***(Tab. 1, column 2)*** and that b) the differentiation of the terms may depend on the discipline ***(Tab. 1, column 1).*** In addition, the researchers analysed who along the production process each action instruction may concern ***(Tab. 1, column 3).*** This analysis revealed that c) some action instructions affect all stakeholders and impact every stage in the product life cycle (e.g. 'design for circularity'). Therefore, some action instructions are difficult to interpret for the purposes of design and, therefore, difficult to apply. Other action instructions, in turn, are precise: for instance, the action instruction 'design for material separability' concerns a process which can, for example, chemically separate yarn blends.

In order to clarify who along the product life cycle the different action instructions may concern, the researchers allocated each action instruction to one or more specific stakeholders in a circular network. The circular network is based on 'The great recovery: redesigning the future' (RSA, 2014).

Assigning each action statement to one or more stakeholders shows the design scope along the entire product design, production process and life cycle. The design researchers (product, textile and material) and the environmental scientist discussed clustering the action statements in an expert workshop to achieve the first complexity reduction.

The guiding questions were: which action instructions relate to each other in terms of content? Under which terms can the action instructions be grouped? Are the cluster terms precise and understandable for the different stakeholders? The design researchers consolidated the 117 action instructions along the guiding questions into seven thematic clusters. The clusters were each given a representative cluster term based on existing literature. ***See example, Fig.1.***

The following seven thematic clusters were defined: The first two cluster topics, ***'delight' and 'functionality' (1,2),*** relate to instructions for action around classic product design and are also relevant to product sustainability. These two action instructions concern that a product is only of value to the user over a long period if it provides pleasure, meets a need and simultaneously fulfils its function.

The third cluster topic, ***'product circularity' (3)***, comprises instructions for action to ensure that a product can be recycled as a whole or as an individual part/semi-finished product. The fourth cluster topic, ***'product life cycle'(4)***, provides instructions for action regarding a choice of materials and processes adapted to the life cycle. The fifth cluster topic ***'material health' (5)*** concerns instructions for action in terms of avoiding harmful substances in the product or the production process. The sixth cluster topic, ***'material circularity' (6)***, summarises action instructions to return the material used to the biological or technical cycle as far as possible in order to minimise non-recyclable waste generation. ***'Effective production' (7)*** forms the last cluster topic, which comprises the action instructions from the production phase of products.

Accordingly, the following seven cluster terms are proposed: ***'design for delight' (1) 'design for functionality and usability'(2)***, ***'design for product circularity' (3), 'design for appropriate lifespan' (4), 'design for material health' (5), 'design for material circularity and minimal waste' (6)*** and ***'design for effective production' (7).*** These were named several times if action instructions were applied to several cluster terms.

In order to reduce the complexity of the clustering, different ordering principles and hierarchies were tried out: along a shell principle from the rough to the detailed, a material-centric perspective and a product-centric perspective.

Applied design research in the development of sustainable textile products has shown that concrete questions and challenges arise along the previously linear process value chain and manifest themselves in the specific product. Moreover, the product-centric approach seems closer to the designers in practice than another theoretical concept.

Based on these considerations, the action instructions were mapped along a product and product life-cycle-centred perspective as an ordering principle. The product life cycle was structured into the five product life phases, ***'production', 'use', 'extended use', 're-use'*** and ***'end of life'.*** The allocation of the 117 action instructions to the product life phases was carried out in an expert workshop with design researchers who bring knowledge from application-oriented research projects in collaboration with the textile industry (Texrecycling 4.0 (Research Group Products & Textiles, 2020), Texcycle (Research Group Products & Textiles, 2019) Texcircle (Research Group Proudcts & Textiles, 2022) and recolore (Research Group Proudcts & Textiles, 2022). The criterion for allocation to the product life phases was the potential impact of the action instruction in the corresponding life cycle stage. For the hierarchisation of the assignment ***(Fig. 2)***, a dedicated product perspective was adopted. In Fig. 2, visible and invisible aspects of a product from the consumer perspective are defined with a line. The five product life phases are shown vertically. In the first line of the horizontal, the cluster terms (1,2) concern the visible aspects of a product. These first two cluster terms are not considered further in this research because they are already covered by classical product design. The second row of the horizontal line shows the five cluster terms (3, 4, 5, 6, 7) that

1 [*1]	**2** — Design for X' - recommendations	**3** — Stakeholderinvolvement [*2]
D	Design for permanence	D / RM / ME / M / BC / CU
	Design for transience	D / RM / ME / M / BC / CU
D	Design for use	D / M / BC
	Dematerialization	D / AE / BC / CU
	Substitution	D / PM / RM / ME / M / BC
	Localisation	RM / ME / M / I / BC
	Transmaterialization	D / BC
	Design for informationalization	BC / CU
	Design for durability	D / PM / ME / M / BC
	Design for reuse (product / material)	D / ME / RM / M / BC
	Design for disassembly	D / PM / ME / RM / M / BC
	Close the loop	D / AE / I / PM / RM / ME / M / BC / CU
	Design for effectiveness	D / AE / I / BC / CU
	Design for systems	D / AE / I / PM / RM / ME / M / BC / CU
D	Designing in greater durability	D / PM / ME / M / BC
	Designing in versatility	D / ME / M / BC
	Designing in multifunctional uses	D / ME / M / RM / BC
	Designing in modularity	D / ME / M / RM / BC
	Designing in low wash frequency	D / ME / M / BC / CU
	Design for environment	D / AE / I / PM / RM / ME / M / BC / CU
	Design for disassembly	D / PM / ME / RM / M / BC
	Design for disposal	D / AE / PM /RM / ME / M / BC
	Codesign with the supply chain: better chemicals, yarns and fabric	D / RM / ME / M / BC
	Codevelop with the supply chain for circular materials and components	D / RM / ME / M / BC
	Customization of existing materials in supply chain for new textile applications	D / RM / ME / M / BC
D	Designing with quality and lifecycles in mind	D / PM / RM / ME / M / BC
	Design for several lifecycles	D / PM / RM / ME / M / BC
	Creating something more meaningful and special for the end user	D / BC
	Design for quality and long-term use	D / ME / M / BC
	Emotional design	D / BC
	Design for easy repair	D / ME / M / RM / BC
	Design with new business modell	D / I / PM / RM / BC / CU
	Design for recycled materials	D / RM / ME / M / BC
	Avoid harmful toxic chemicals and substances	D / AE / I / PM / RM / ME / M / BC / CU
	Design for recycling	D / PM / RM / ME / M / BC
	Design for transformation	D / AE / I / PM / RM / ME / M / BC / CU
D	Reuse	D / RM / ME / M / BC
	Repair	D / PM / RM / ME / M / BC / CU
	Refurbishment	D / RM / ME / M / BC
	Remanufacture	D / RM / ME / M / BC
	Design for recycling	D / PM / RM / ME / M / BC
	Design for parts harvesting	D / RM / ME / M / BC
	Design for material separability	D / PM / RM / ME / M / BC
	Design with recycled materials	D / PM / RM / ME / M / BC
	Design for part recovery	D / RM / ME / M / BC
D	Design for attachment and trust	D / BC
	Design for durability	D / PM / RM / ME / M / BC
	Design for standardization and compatibility	D / PM / RM / ME / M / BC
	Design for ease of maintenance and repair	D / PM / RM / ME / M / BC
	Design for and adaptability and upgradability	D / PM / RM / ME / M / BC
	Design for dis- and reassembly	D / PM / RM / ME / M / BC
D	Narrative	D / BC
	Detachement	CU
	Surface	D / ME / M
	Attachment	D / BC / CU
	Fiction	D / BC / CU
	Consciousness	D / BC / CU
E	Design out waste	D / ME / M / BC
	Employ the right materials for appropriate lifetime and extended future use.	D / RM / ME / M / BC
	Design for durability	D / RM / ME / M / BC
	Design for cyclability	D / RM / ME / M / BC
	Regenerative materials, regenerative water, regenerative energy	D / PM /RM / ME /M / BC
	Upgrade, repair, and maintenance of products while they are still in-use	D / RM / ME /M / BC
	Customer / consumer collaboration	D / I / RM / ME /M / BC
	Valorise waste streams - closed loop	D / AE / I / PM / RM / ME / M / BC / CU
	Valorise waste streams - open loop	D / AE / I / PM / RM / ME / M / BC / CU
E, D	Reduction in use of virgin material	D / PM / RM / ME / M / BC
	Elimination of waste – design out waste and pollution	D / ME / M / BC
	Designing products with their next lives in mind	D / PM / RM / ME / BC
	Design products for durability	D / PM / ME / M / BC
	Design products for personalization	D / PM / RM / ME / M / BC / CU
	Design products for upgradability	D / M / BC / CU
E	Circular Supplies: provide renewable energy	I / PM / M / BC
	Circular Supplies: bio-based input material to replace single life cycle inputs	D / RM / ME / M / BC
	Circular Supplies: fully recyclable material input, replace single life cycle inputs	D / RM / ME / M / BC
	Recover useful resources/energy out of disposed products or by-products.	D / I / PM / RM / ME / M / BC
	Product life Extension: repairing	D / PM / M / BC
	Product life Extension: Upgrading	D / RM / ME / M / BC
	Product life Extension: reselling	D / I / RM / BC
	Product as a service: Offer product access and retain ownership	D / I / BC / ME / M / CU
D	Rethink	D / AE / I / BC
	Design for contin-use	D / AE / I / PM /RM / ME / M / BC, CU
	Design to slim down	D / AE / I / PM /RM / ME / M / BC
	Design for recyclability	D / PM / RM / ME / M / BC
	Design for renewability	D / PM / RM / ME / M / BC
D	Long life guarantee and product satisfaction	D / PM / ME / M / BC
	Product attachment and emotionally satisfying design	D / BC / CU
	Customization	D / PM /RM / ME / M / BC / CU
	Halfway products and modular structures	D / ME / M / RM / BC
	Co-creation and open-source design	D / BC / CU
	Services	D / AE / I / PM / RM / ME / M / BC / CU
	Design services	D / AE / I / PM / RM / ME / M / BC / CU
	Services for intensive and longer utilization	D / I / BC / CU
D	Design for sorting	D / PM / ME / M / BC
	Design for longevity should be required prior to 'design for recycling'	D / PM / ME / M / BC
	Design modular product structures that allow separation of different materials	D / RM / M / BC
	Use only a single material (mono-material design)	D / RM / M / BC
	Design for a specific recycling stream	D / RM / ME /M / BC
	Transparency	PM / RM / ME / M / BC
D	Intentional fashion design defined by recycling technologies	D / PM / RM / ME / M / BC
	Designed that makes them easy to take apart and separate parts and materials	D / RM / ME / M / BC
	Design garments using only a single material (i.e., monomaterial design)	D / RM / ME / M / BC
	Transparency	D / PM / RM / ME / M / BC
	Design garments with a certain use context and defined lifespan in mind	D / RM / ME / M / BC / CU
C, A	Design for effectivity	D / PM / RM / ME / M / BC
	Design for material health	D / PM / RM / ME / M / BC
	Design to reduce water use	D / PM / RM / ME / M / BC
	Design with renewable energy	PM / RM / ME / M / BC
D	Design for clothing	D / BC / CU
	Design for fashion	D / BC / CU

Tab. 1
Listing of extracted design guidelines from the literature.

***1 Scholarly Discipline:**
A = Architecture / C = Chemistry / D = Design / E = Economy

***2 Stakeholderinvolvement based on (RSA, 2014)**
D = Design
AE = Academics & Education
I = Investors
PM = Policy Makers
RM = Resource Management
ME = Material Experts
M = Manufacturers
BC = Brand, Company
CU = Customer / User

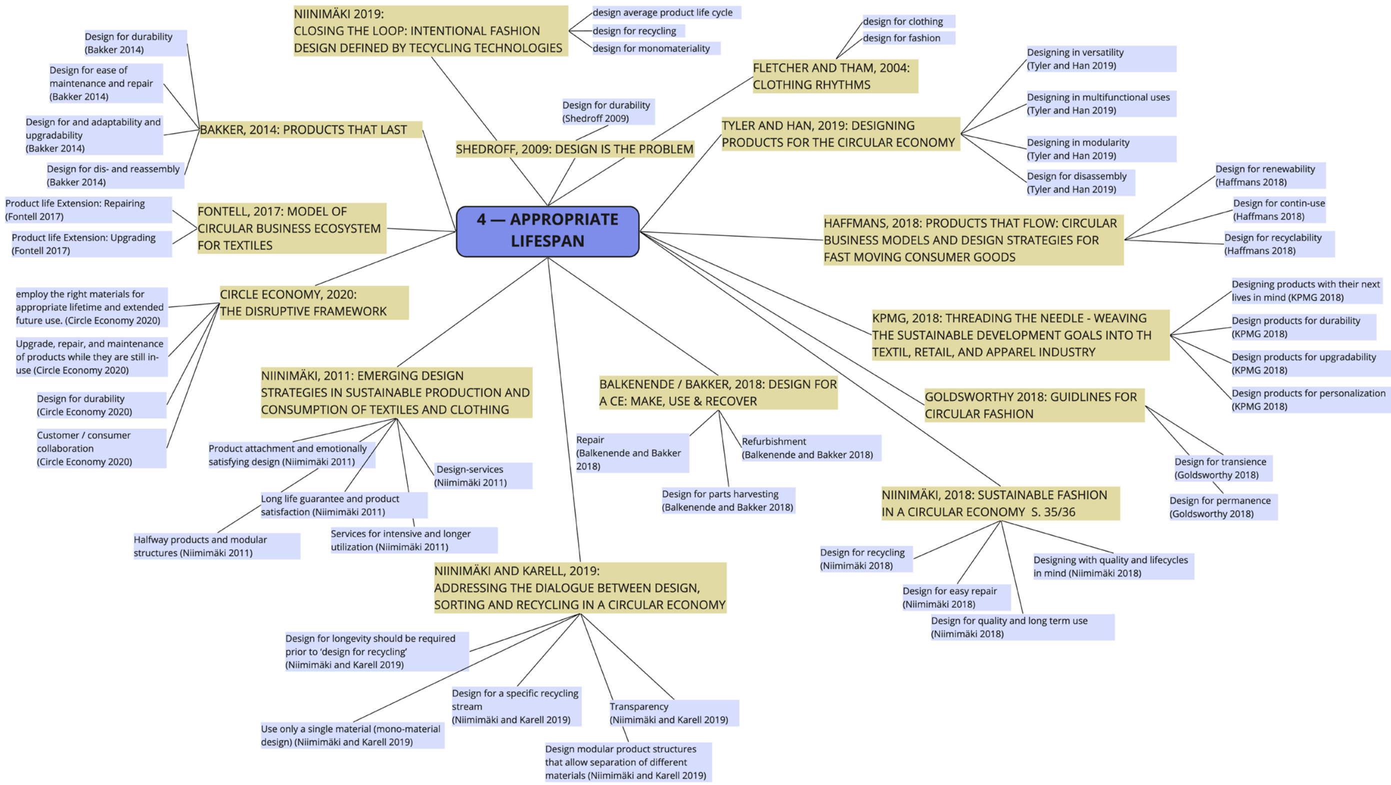

***Fig. 1** shows the example of the clustering of the guidelines using the cluster term 'appropriate lifespan'. The researchers marked the analysed publications in green and the extracted guidelines in light blue.*

concern the invisible aspects of a product. These include new and relevant aspects for improved product sustainability that must already be considered in the design process.

After allocating the action instructions to the five product life phases, the action instructions were linked with lines with the five cluster terms (3, 4, 5, 6, 7) that concern the invisible aspects of a product.

Figure 2 ***(Fig. 2)*** shows that action instructions could be linked to one, two or at most three phases of life. For the assigned action instructions, summary terms were determined based on the literature, which serves as an ordering principle, and must be checked further for their scientific correctness and understanding in practice.

This paper proposes the following summary terms for the action instructions in the respective product life cycle phase: ***'production' phase*** – 'design for appropriate production site', 'design for minimal production waste', 'design for processes using minimal or renewable resources' and 'design for social fair production'; ***'use' phase*** – 'design for alternative use models', 'design for longevity' and 'design for ephemerality'; 'extended use phase' – 'design for repair options', 'design for upgradability' and 'design for modularity'; ***'reuse phase'*** – 'design for remanufacture' and 'design for reuse'; ***'end-of-life phase'*** – 'design for recycling and recovery', including a further subdivision into the terms 'design for renewable feedstock', 'design for material separation' and 'design for monomateriality'.

After the complexity of the clustering had reached the limit of readability in tables and mind maps, figure 3 was translated into a graphical visualisation, hereafter called the 'design decision tree', and an explanatory key was created for this and linked to relevant literature (***Fig. 3***). To show existing interdependencies between the action instructions, the terms were linked in a last step.

With the graphical visualisation along the product life cycle, improved clarity of the individual action instructions could be achieved. Furthermore, in this visualisation, it was also possible to make the dependencies visible by linking the individual action instructions with each other.

On the one hand, the dependencies can be read as conditions for designing a product for a specific cycle. On the other hand, these dependencies open up the scope of action for design.

Results

Of 70 hits from the literature search, 16 publications were relevant for design. This resulted in a total of 117 action instructions related to design. Some of these action instructions were named similarly but interpreted differently depending on the discipline and the party they were addressed to or had different meanings despite the similar names. This result illustrates the complexity of the issue of design and sustainability and underlines the need for assistance with translation into design practice.

The assignment of the various stakeholders to the individual action instructions showed that it was always possible to assign at least two stakeholders a role in the individual action instructions, and in most cases this number was as high as five to nine stakeholders. It also became apparent that design has a

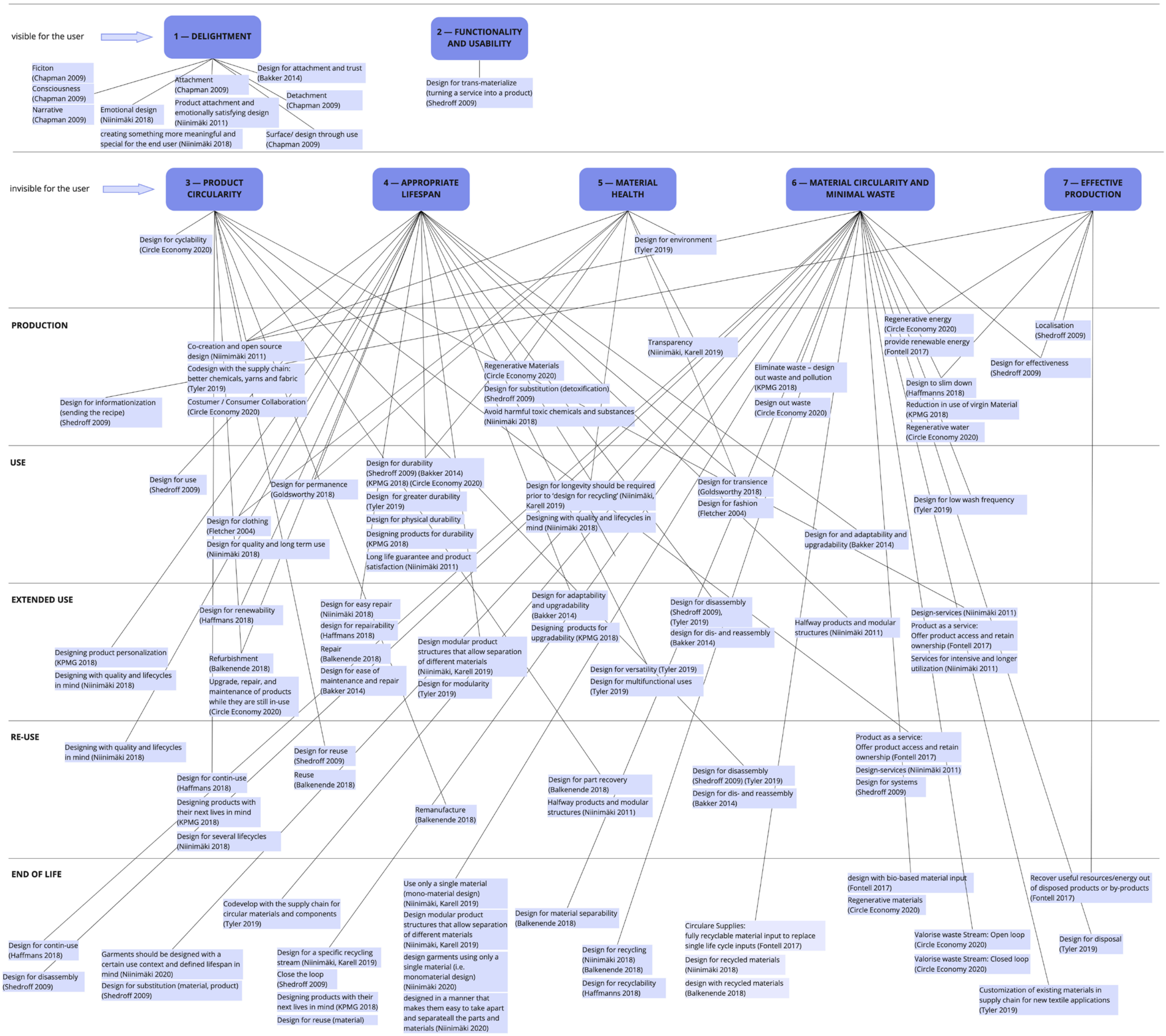

Fig. 2 *Classification of action instructions in a product life cycle linked to cluster terms 3, 4, 5, 6, 7.*

role to play in almost all action instructions. Design could be excluded in only nine action instructions. The allocation made it clear that there is considerable scope for action in product design. Although these actions must be performed by different stakeholders throughout the product life cycle, they must be taken into account accordingly in the design phase. There is scope for action at a strategic level, such as in sustainable company/brand strategies, and at an operational level in the processing of pre- and post-consumer waste into secondary raw materials, to give just a few examples.

A further result was the mapping of the clustered action instructions along the product life cycle. The mapping made it possible to integrate the action instructions into a new visualisation taking into account two perspectives.

Firstly, a product-centred perspective was adopted for the action instructions. This perspective corresponds to that of the product designer. The product-centred perspective defines the product as the starting point for all action instructions.

Secondly, the action instructions were classified according to the product life phases of ***'production', 'use', 're-use', 're-manufacturing'*** and ***'recycling'***. The classification of the action instructions across the product life cycle makes it possible to anticipate all phases that the product can potentially go through in circular cascades.

The mapping thus gave rise to an initial, product-centred ordering principle that is focused on design practice and enables possible action instructions to be recorded at a glance according to the phase in the product life cycle. Furthermore, an initial version of a graphical visualisation of this mapping was created. The graphical visualisation uses visual methods of information organisation, thus making the various information dimensions more readable.

In contrast to the preceding mapping, it was also possible to show interdependencies between individual action instructions in the graphical visualisation. This makes the interdependencies visible as conditions for designing a product for a specific cycle. The graphical visualisation helps to communicate this complex topic to those working in design practice.

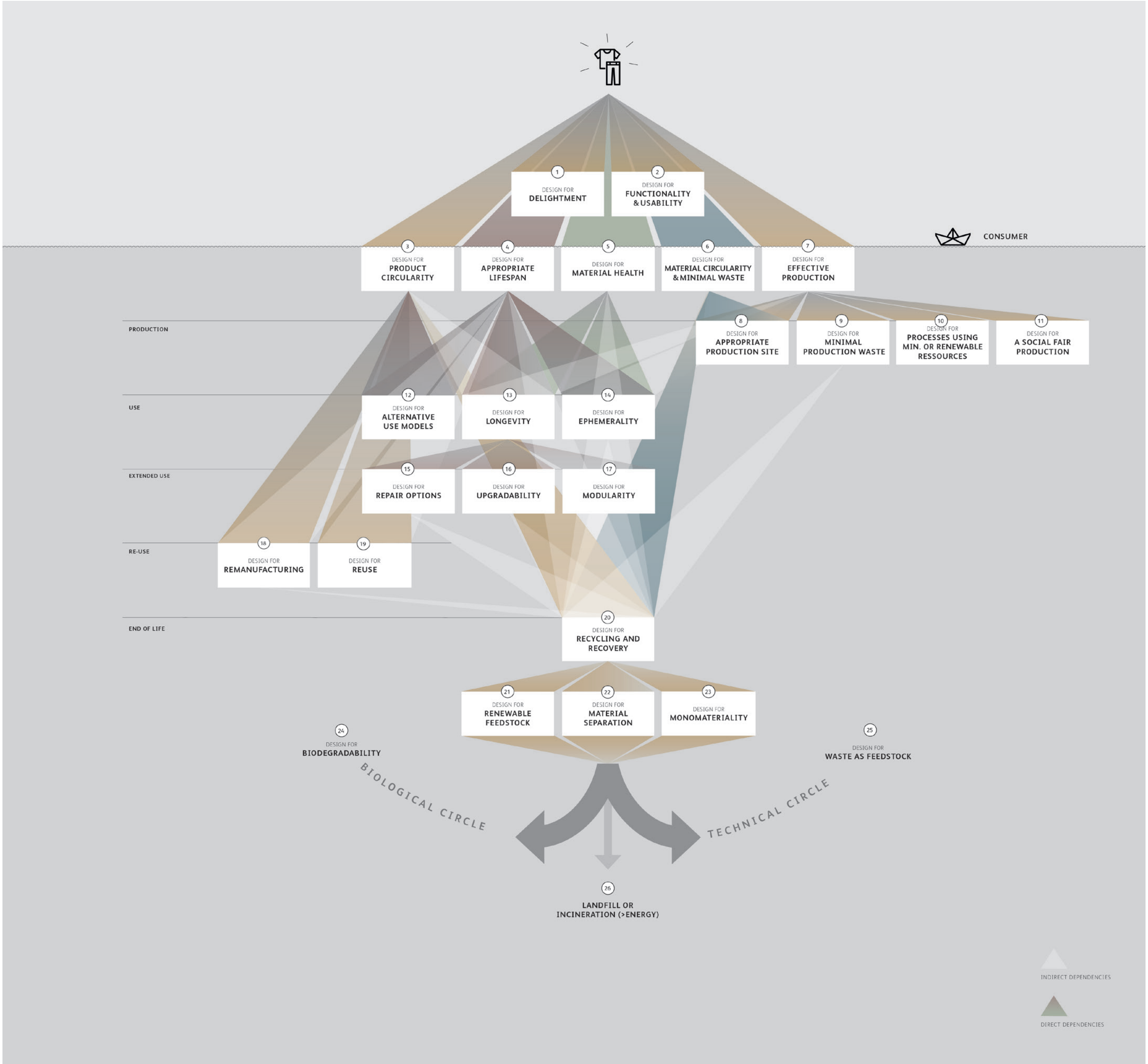

***Fig. 3** Graphical form, hierarchy, assignment and interconnection of the 23 proposed cluster and assignment terms within the five product life phases. (Adler et al., 2021)*

An explanatory key and sources were added to the graphical visualisation, enabling more in-depth research into the approaches.

Reflection

The motivation behind this research paper and publication was the realisation that the design concepts for improved product sustainability and circularity that have existed for some time in design research do not seem to be being implemented in design practice. This is described in theory (Niinimäki & Hassi, 2011), is consistent with insights from application-oriented research projects with industrial partners and is reflected in the steadily rising rates of primary fibre consumption (Textile Exchange, 2021). The goal was to identify the challenges to design practice and look for means of support in tackling them. The key research question was how theoretical design strategies and concepts can help to achieve more product sustainability and circularity in design practice.

The results of the literature search and analysis can be interpreted as possible reasons as to why the existing action instructions are difficult to apply in design practice. There are numerous action instructions which are named similarly but do not mean the same thing. This fact makes the search for specific answers to practice-related questions difficult. In addition, the application focus of these instructions, for example with regard to the phase in the product life cycle, is often unclear at first glance.

Improving the clarity and content-related structuring of the action instructions and classifying them according to a logic that is common in design practice should help to close the gap between theory and practice. The allocation of stakeholder involvement undertaken in the literature analysis confirmed the key role that is often attributed to design in relation to improved product sustainability. The allocation showed that design is involved in almost every action instruction. However, the analysis also showed that improved product sustainability will only be possible with the interaction of specific, relevant stakeholders (brand/company, manufacturer, resource management, material experts, etc.). In a circular, sustainable product development process, the designers perform a key role in the sense that they function as hubs for the (co-)design of circular processes, materials and products. This can only succeed if the relevant stakeholders are involved by means of jointly taken, supported decisions of a financial, environmental, social and organisational nature. An extension of product use through re-use, for example, is partly a business issue. Such circular use, with an improvement in longevity, reparability and/or refurbishment, must already be incorporated at the material and product design level from the outset. This means that, although relevant decisions are already taken at the design stage, the associated solutions must be developed together with the relevant stakeholders (brand/company, manufacturer, material expert and resource management). This underlines the responsibility, described at the start of this paper, that design has in relation to the 80% of product-related environmental costs which are decided on in the design phase. The work of collecting the action instructions, clustering and then mapping them is ultimately condensed in the graphical visualisation, the design decision tree. The entire process can be described as one of iterative consolidation and information organisation, with the goal of improving clarity.

The design decision tree can be used to depict the life cycle of products, relevant action instructions and the complex interactions between the action instructions. With its product-centred nature and top-down structuring, it provides a starting point from which the individual product life phases can be thought through on a step-by-step basis. Furthermore, this form of visualisation also shows that there is no one single, universally valid strategy; the mapping encourages the testing of different circular variants for a product. This approach therefore has the potential to provide designers with low-threshold assistance in making decisions with regard to the circularity of the product being designed, or at least to raise their awareness of this issue.

However, simplification always involves the risk of omitting relevant considerations. To counteract this, an appendix provides a brief description and sources for more in-depth research, comparable with a glossary in a book. An application briefing on using the design decision tree will be a further measure that helps with communicating the design decision tree. Another gap emerges between the aspiration of theory-based action instructions and the processes available in practice. Theoretical action instructions are only useful if the relevant processes are available in industry. A monomaterial-based approach, for example, only makes sense if there is a corresponding process for recycling the material. Such matters must constantly be clarified.

The aspiration for the design and the involved stakeholders is that they keep the entire product life cycle in mind and possess extensive expertise in order to be able to make sustainable design decisions. After all, all decisions are ultimately reflected in the real product – its manufacturing, use and disposal/the process by which it is fed back into a technical or biological cycle – and not in the theory. With this in mind, the graphic provides – in comparison to the 70 hits and 117 action instructions from different disciplines in design-related literature – an initial overview of possible design interventions and offers designers working in practice a low-threshold entry point into the subject of improved product sustainability – as a contribution towards closing the gap between design research and practice in the area of improved textile product sustainability.

Outlook

Initial informal conversations and tests in relation to the design decision tree with designers working in practice and within the research group have shown that, as a translation of existing theoretical action instructions for design practice, it is fundamentally regarded as expedient and useful. The initial feedback shows that the design decision tree has the potential to enjoy a wide range of uses. These include using it as argumentation for sustainable design decisions vis-à-vis customers, to identify gaps in companies' own sustainability strategies, as a basis for discussions on the choice of materials, and as support in teaching. However, the feedback also showed that, in its initial, current form, the design decision tree is not self-explanatory and does require some communication. In this regard, it must be clarified how its potential use can be communicated to designers – for example in the form of briefings for companies. One of the next steps will be to review the form and potential application of the design decision tree in detail with designers working in practice on the basis of case studies. This will show whether the intended integral application of such a design decision tree is meaningful and useful and whether it will have the intended benefit for design practice. It will also be possible to use feedback from the case studies to further develop the design decision tree in a user-centred way. The terminology will be checked to ensure that it is generally comprehensible and the stakeholder involvement in design practice/the corresponding decision-making process will be evaluated in future research projects. In this context, it will be clarified whether and how the stakeholder involvement described can be meaningfully integrated into the individual action instructions in the design decision tree. In addition, specific gaps in research will be identified along the design decision tree and addressed with research partners from practice.

Acknowledgements

The authors would like to thank all industry and network partners, the funding agency Innosuisse and the research team of the Texcircle applied research project, which this work is part of, for their valuable time, advice and feedback. Further thanks go to the Products & Textiles Research Group of the Lucerne University of Applied Sciences and Arts for their involvement in the various workshops to develop the design decision tree. The research work has been further enlarged upon in the ongoing PhD thesis with the working title 'The design as an enabler for consistently sustainable textile products' (Adler, n.d.).

References

Adler, F. (n.d.), 'Das Design als Enabler für konsequent nachhaltige Textilprodukte'. Available at: URL https://www.hslu.ch/de-ch/hochschule-luzern/forschung/projekte/detail/?pid=6108 (accessed 30 September 2022)

Adler, F. , Schmidt, L., Weber Marin, A., Tomovic, T., Willi, B. (2022), 'Texcircle: Circularity for Textiles. Ein Zwischenbericht / Inno-Suisse Projekt-Nr. 41278.1 IP-SBM.' Available at: https://zenodo.org/record/6420873#.YzaWZy0evUJ (accessed 30 September 2022)

Adler, F., Schmidt, L., Weber Marin, A., Willi, B. (2021), 'Design Decision Tool für eine nachhaltige Produktentwicklung'. Available at: https://zenodo.org/record/5127157#.Yzafgi0evUJ (accessed 30 September 2022)

Bakker, C., den Hollander, M., van Hinte, E., Zijlstra, Y. (2014), 'Product That Last - Product design for circular business models'. Delft Librery, Delft.

Balkenende, R., Bakker, C. (2018), 'Designing for a circular economy: Make, use and Recover Products'. In: Sustainable Fashion in a Circular Economy; Niinimäki, K., Ed.; Aalto University: Helsinki, Finland 76–95.

Bocken, N.M.P., De Pauw, I., Bakker, C., van der Grinten, B. (2015), 'Product design and business model strategies for a circular economy'. Journal of Industrial and Production Engineering. https://doi.org/10.1080/21681015.2016.1172124

Campbell-Johnston, K., Vermeulen, W.J.V., Reike, D., Brullot, S. (2020), 'The Circular Economy and Cascading: Towards a Framework'. Resources, Conservation & Recycling: X 7, 100038. https://doi.org/10.1016/j.rcrx.2020.100038

Chapman, J. (2009), 'Design for (emotional) Durability'. Design Issues 25, 29–35.

Circle Economy (2020), 'The Disrupt Framework'. Circle economy.

Ellen MacArthur Foundation (2017), 'A new textiles economy: Redesigning fashion's future'.

Ellen MacArthur Foundation (2013), 'Towards the Circular Economy, Economic and Business Rationale for an Accelerated Transition'. Ellen MacArthur Foundation: Cowes, UK.

European Commission (2018), 'Sustainable Product Policy'. Available at: https://ec.europa.eu/jrc/en/research-topic/sustainable-product-policy. (accessed 30 September 2022)

Fletcher, K., Tham, M. (2004), 'Clothing rhythms', in: Enternally Yours, Time in Design. 010 Publishers, Rotterdam, pp. 254–274.

Fontell, P., Heikkilä, P. (2017), 'Model of circular buisness ecosystem for textiles'.

Ghisellini, P., Cialani, C., Ulgiati, S. (2016), 'A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems'. Journal of Cleaner production 114, 11–32.

Goldsworthy, K., Earley, R., Politowicz, K., others (2019), 'Circular Design Speeds: prototyping fast and slow sustainable fashion concepts through interdisciplinary design research'.

Haffmans, S., van Gelder, M., van Hinte, E., Zijlstra, Y. (2018), 'Product That Flow - Circular business models and design strategies for fast-moving consumer goods'. BIS Publishers, Amsterdam.

Hickel, J. (2021), 'The degrowth imperative - how to create a just and sustainable economy'. Presented at Textile Exchange Conference 2021.

Karell, E., Niinimäki, K., (2019), 'Addressing the Dialogue between Design, Sorting and Recycling in a Circular Economy'.

KPMG (2018), 'Threading the needle Weaving the Sustainable Development Goals into the textile, retail, and apparel industry'. KPMG.

McAloone, T.C., Bey, N. (2009), 'Environmental improvement through product development: A guide. Danish Environmental Protection Agency'.

McDonough, W., Braungart, M. (2010), Cradle to cradle: Remaking the way we make things. North point press.

Niinimäki, K., Hassi, L. (2011), 'Emerging design strategies in sustainable production and consumption of textiles and clothing'. Journal of Cleaner Production 19, 1876–1883. https://doi.org/10.1016/j.jclepro.2011.04.020

Niinimäki, K., Karell, E. (2020), 'Closing the loop: Intentional fashion design defined by recycling technologies', in: Technology-Driven Sustainability. Springer, pp. 7–25.

Niinimäki, K., others (2018), 'Sustainable fashion in a circular economy'. Aalto University.

Research Group Products & Textiles (2022), project 'recolore'. Available at: https://www.hslu.ch/de-ch/hochschule-luzern/forschung/projekte/detail/?pid=6079 (accessed 30 September 2022)

Research Group Products & Textiles (2020), project 'Texrecycling 4.0.' Available at: https://www.hslu.ch/de-ch/hochschule-luzern/forschung/projekte/detail/?pid=4388 (accessed 30 September 2022)

Research Group Products & Textiles (2019), project 'Texcycle'. Available at: https://www.hslu.ch/de-ch/hochschule-luzern/forschung/projekte/detail/?pid=3921 (accessed 30 September 2022)

Research Group Proudcts & Textiles (2022), project 'Texcircle'. Available at: https://www.hslu.ch/de-ch/hochschule-luzern/forschung/ausgewaehlte-projekte/texcircle/?sourceurl=/texcircle (accessed 30 September 2022)

RSA, T.G.R. (2014), 'Designing for a circular economy: Lessons from The Great Recovery 2012 – 2016'. RSA The Great Recovery.

Šajn, N. (2019), Environmental impact of textile and clothes industry 10.

Shedroff, N. (2009), Design Is The Problem - The future of design must be sustainable. Rosenfeld Media, New York.

Stebbing, P., Tischner, U. (2015), 'Changing Paradigms: Designing for a Sustainable Future'. University School of Arts, Design and Architecture.

Textile Exchange (2021), 'Preferred Fibre & Materials: Market Report 2021'.

Tyler, D.J., Han, S.L.-C. (2019), 'Designing Products for the Circular Economy', in: Technology-Driven Sustainability - Innovation in the Fashion Supply Chain. pp. 93–116.