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Addressing the Dialogue between Design, Sorting and Recycling in a Circular Economy

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Abstract: What kinds of implications does 'design for recycling' have for the designer's role and practice in the context of textiles and fashion? In this paper, we approach this question by discussing the problem of low textile recycling rates alongside a disconnection between clothing design and textile recycling. Qualitative interviews with design, sorting and recycling experts were conducted to gather insights into the challenges and requirements of closed-loop recycling. The research findings underline the importance of an active dialogue between these stakeholder groups, which calls for novel ways of sharing knowledge of the latest advancements in sorting and recycling technologies. In addition, the study brings forth the priority order of design considerations and proposes 'design for sorting' as a new strategy for textile circularity. The paper contributes to the ongoing discussion on design practice in a circular fashion system and the required changes in the mind-set of the entire industry.

Keywords: Circular economy, Clothing design, Design for recycling, Textile recycling, Textile sorting

1. Introduction

Increasing volumes of clothing consumption and textile waste create substantial environmental, social and economic problems that stakeholders across the textile and clothing industry must jointly address. The pressing need for more sustainable production practices in tandem with technological developments and changing consumer demands forces the industry players to rethink their business processes and models. The redesign of the industry has begun slowly in recent years. Non-profit initiatives, such as Global Fashion Agenda (2018a), have emerged to facilitate industry-wide collaboration and set a mutual direction towards a more sustainable industry. Various transdisciplinary projects (e.g. Trash-2-Cash, Mistra Future Fashion) have received considerable financial support to increase systemic understanding among multidisciplinary teams and thereby co-create sustainable innovations and novel practices for the fashion system.

The Circular Economy (CE) is the guiding concept in these circles. This concept challenges the linear production-consumption model, having potential to tackle social and environmental problems without compromising economic benefits. Based on the closed-loop approach (Braungart & McDonough, 2002), design tools, new business models, manufacturing methods, textile sorting and

recycling technologies are emerging and attracting growing research interest to enhance reuse and recycling of textiles.

Today, global recycling rates of waste clothing into new applications of a similar quality (more precisely upcycling) are estimated to be less than 1% (Ellen MacArthur Foundation, 2017). Considering the estimates that show total clothing sales will triple by 2050 (Ibid.) in step with the rise of the global 'middle class', reuse and recycling of waste clothing must be enabled on a larger scale. In the quest for improved textile circularity, multiple goals have been initiated: These include, for instance, the 2020 Circular Fashion System Commitment (Global Fashion Agenda, 2018a), the Nordic textile reuse and recycling commitment (Fråne et al., 2017), and H&M's commitment to a climate positive value chain (H&M, 2018). These examples imply both global, regional and company level understandings of the industry's challenges and a shared vision of a closed-loop material system.

Traditionally, textile waste has served as material input for mechanical fibre recycling, which does not produce the best quality fibre: In most cases, recycled materials are blended with virgin raw materials to increase the quality (Niinimäki, 2018). New chemical and thermal fibre recycling processes are emerging, showing potential to enable regeneration of high-quality fibres at scale based on pre- and post-consumer textile waste. However, these new methods have their limitations. Selection of materials suitable for each regeneration process calls for careful sorting of textile waste and accurate fibre identification (Elander & Ljungkvist, 2016; Niinimäki, 2018). Automatic sorting technologies (under development) provide means to tackle this issue but they come with further restrictions regarding aspects such as colours, material blends and textile surfaces (Wedin et al., 2017; Zitting, 2017; Fibersort, 2018). These aspects pose obstacles to sorting and recycling efficiency, which need to improve considerably to pave the way for an increase in closed-loop textile recycling (Ljunqvist et al., 2018).

We argue that the efficiency of the new technological processes (sorting and recycling) could be influenced already at the level of design, as that is where material and structural decisions concerning products are made. However, the route from design to textile recycling is challenging due to a disconnection between the industry processes (Ellen MacArthur Foundation, 2017). Despite the substantial efforts in connecting industry participants (as described above), Elander and Ljungkvist (2016) report that there is a lack of communication on textile circularity between stakeholders.

This paper addresses the problem of low textile recycling rates alongside the disconnection between clothing design and closed-loop textile recycling. Considering the earlier observations on the lack of communication (Elander & Ljungkvist, 2016; Ellen MacArthur Foundation, 2017) we aim to widen the discussion on how textile recycling rates could be improved. Specific attention is paid to the role and responsibility of design in that endeavour. While in the linear system (design-manufacturing-sales-use-dispose) the designers' responsibility is often limited to style, quality and manufacturing steps, in the closed-loop system we should come to understand designers' responsibilities more widely. In a circular economy, the goal is to maintain the value of products and materials as long as possible. Materials should be recycled several times, meaning that all products are designed to fit a closed-loop system where all aspects support circularity (Niinimäki, 2018). This brings forth new challenges for designers. New knowledge is required on how to design for recycling in practice.

Unlike the linear fashion system, the design process in a closed-loop system has not been studied extensively. Han et al. (2017) have compared clothing redesign with standard design processes, concluding that the differences in terms of the design brief, research and material sourcing directly

change the creative process and dependency on other stakeholders. Understanding the different features of these processes better enables sustainable practices on a larger scale (Han et al., 2017). Aligned with this view, we therefore ask: What kinds of implications does 'design for recycling' have for the designer's role and practice in the context of textiles and fashion? With whom should they collaborate and how can they do so?

Based on the literature, industry experiences, and the knowledge gained from different research projects, the authors have identified the design, sorting and recycling phases (highlighted in figure 1) as the core areas for the construction of new knowledge required for a circular fashion system. Direct collaboration between industry stakeholders is needed to create a functional closed-loop fashion system. Sorters and recyclers represent pivotal stakeholder groups with whom designers need to collaborate in order to design garments suitable for closed-loop recycling. Hence, in this paper we focus on these three phases, aiming to widen the understanding of their interdependency and further implications for design practice. The paper contributes to the ongoing discussion on clothing designers' roles in a circular economy and the required changes in the mind-set and the organisation of the entire textile industry.

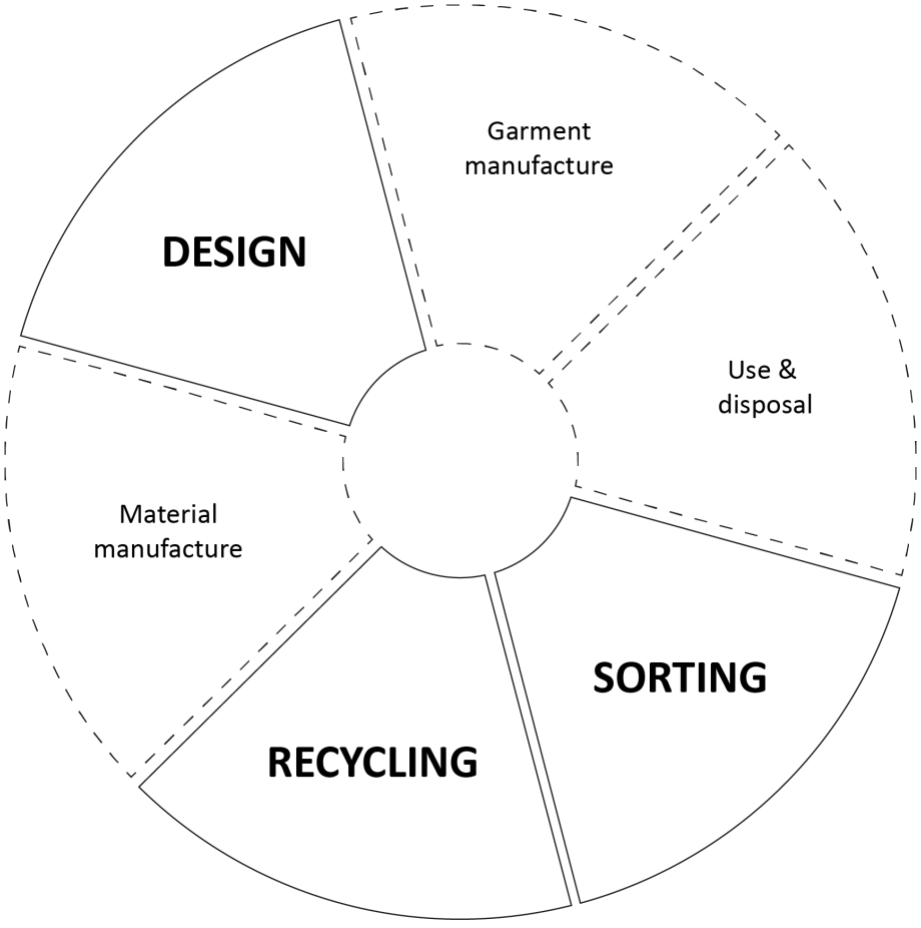

Figure 1. Design, sorting and recycling represent the pivotal phases in the circular supply chain when targeting new knowledge on how to design for recycling.

2. Methodology

The paper provides an exploratory investigation of a designer's role and practice in the context of closed-loop textile recycling. An exploratory research approach was considered suitable for this study as clothing design in CE is a relatively new field of inquiry that is in constant flux. Novel technologies are rapidly emerging, changing the research landscape in a way that drives us to explore it anew (Stebbins, 2001). This approach allows us to identify vital research gaps, formulate new research questions, and help us position ourselves in this emerging field of study.

To answer the research questions, five (5) expert interviews were conducted (2018) with one clothing designer, one sorting expert and three material scientists working in chemical fibre recycling. Due to the exploratory nature of the research, the small interview sample was considered sufficient for the research purpose. The interviewees were recruited from an EU-funded research project, Trash-2-Cash (2014-2018), that focused on upcycling pre- and post-consumer textile waste into high-value products through chemical recycling (Trash-2-Cash, 2018). The project partners represent multiple stakeholder groups in the textile value chain and shared knowledge of their specific fields over a period of three years in the project (at the time of the interviews) while collaborating on innovative textile applications suitable for closed-loop recycling. The authors of this paper are confident that the project partners have gained a greater understanding of each other's disciplines and practices, which makes the five recruited experts exceptionally suitable interviewees for the study. The areas of expertise of the interviewees are presented in Table 1.

Table 1. Expertise of the interviewees

	Position	Area of expertise
Interviewee 1	Designer	Clothing Design
Interviewee 2	Project manager	Textile Sorting
Interviewee 3	Research professor	Chemical textile recycling
Interviewee 4	Researcher	Chemical textile recycling
Interviewee 5	Postdoctoral Researcher	Chemical textile recycling

The interviews were designed to link clothing design practice with the current stage of textile sorting and chemical textile recycling. The questions were tailored for the interviewees based on their expertise. General discussions were held about their practices in relation to textile circularity. Afterwards, the role and responsibility of design in textile recycling was addressed. Finally, challenges and possibilities of sorting and recycling processes were discussed to identify critical points that designers could consider, thereby helping to improve process efficiencies. Further questions dealt with relations between design, sorting and recycling.

The interviews were audio recorded and transcribed. The analysis was conducted based on open coding. Aspects related to design, sorting and recycling processes, specifically with respect to the challenges faced in closed-loop textile recycling, were sought in the data and

tabled for further discussion. The coding was carried out based on descriptive coding and sub coding (e.g. Challenge for design – Product complexity), which allowed immediate categorisation of design challenges and requirements to the design, sorting and recycling phases (Miles, Huberman, & Saldaña, 2014). The codes were further categorised into relevant themes affecting recycling efficiency (e.g. knowledge, material) in order to help the authors to consider designers' potential contribution to these.

3. Findings

The findings provide a snapshot (Flick, 2009) of current views of closed-loop textile recycling at a specific time (2018) and place (Europe). Interviews supported the understanding that the dialogue between design, sorting and recycling is not active. The relationship between design and sorting was described as a fundamental link – but one which is entirely absent today. Some communication between sorting and chemical recycling seems to exist, but it is still in an early stage due to the readiness levels of the emerging recycling technologies. A dialogue between recycling and design is emerging: Clothing companies are interested in using recycled materials and some collaborations are taking place. However, it seems that information does not flow in the opposite direction (from recycling to design).

The interviewed experts shared rich descriptions of design, sorting and recycling processes, their current state and challenges in closed-loop textile recycling. Challenges based on the experts' perspectives are described below in separate sections: Design, Sorting and Recycling. Tables in each section help to summarise the challenges, further divided into internal and external challenges under relevant themes. In our view, internal and external activities tend to blur when discussing intertwining practices such as those used in clothing supply chains. Hence, such a division was adopted to clarify which challenges can be tackled internally and those which are dependent on external factors. The experts also shared recommendations and ideas for how to improve the (sorting and recycling) process efficiencies, what would be needed, and from which actors. The text concludes with these recommendations.

3.1 Design

A common view is that the design practice in a corporate fashion environment is 'all about the surface', focused on stylistic and functional properties of garments, as described by the design expert. This probably holds true in most companies and brings forth the first internal challenge in garment recyclability: As employees, designers are free to share ideas and introduce alternatives but their role is limited when it comes to decision making and implementing sustainability (aligned with Palomo-Lovinski & Hahn, 2014; Han et al., 2017). Generally, designers work based on a given brief, which predetermines the collection structure, price targets and schedule. According to the design expert, designers at some companies can for example suggest new materials but the final selection is made by product managers, while at other companies designers may have more freedom and responsibility – depending on the size, hierarchy, structure, mind-set and strategy of the employer.

Further challenges at the design level relate to companies' resources: Decisions on how to allocate time and money are made at the managerial level, limiting the time for research work that would be required prior to sourcing sustainable alternatives or novel manufacturing techniques. The challenge with time management is directly linked to product complexity as well. As the interviewed designer aptly illustrated:

> I have to consider multiple questions even in the case of a simple product. If I want to be fully transparent and choose the most ecological and clever alternative, I can use endless amounts of energy and time on the research. - - - The [amount of] research work multiplies when you have more components and suppliers. When you have a heavy outdoor product, in addition to the fabric you have to consider finishing, dye, lamination or coating. There is wadding, lining, sewing yarn, maybe taping. There are zippers, rivets, drawstrings, elastic strings and bands, stoppers, fake fur. Then you put this all together and have to think about how to recycle this.

Through their creative problem-solving ability, designers have the potential to overcome product complexity. However, external challenges such as material availability and a lack of knowledge about sustainable practices were considered to pose substantial barriers in design for recycling. Meanwhile, the limitations of textile sorting and different recycling processes, their requirements for products and materials have not as yet been communicated to designers. Similar challenges have also been reported in earlier studies (Elander & Ljungkvist, 2016; Singh & Ordoñez, 2016; Karell, 2018). Designers can consider all the aspects they are aware of only if they have the appropriate materials and knowledge at hand.

Further external challenges relate to consumption habits and consumer demands. Designers cannot determine how consumers dispose of their products; they can only affect the recycling potential of the product. Secondly, consumers are nowadays used to having a variety of qualities with a specific touch, look and function, which can be achieved only with certain fibre blends (that often are not suitable for recycling). From the design perspective this poses a dilemma in how to balance between aesthetics, function and recyclability.

Table 2. Challenges from the perspective of design

	Internal challenges for design	External challenges affecting design
Designer role	Limited impact on decision making Balancing between aesthetics, functionality and recyclability	Limited impact on products' end-of-life Consumer demands
Knowledge	Company mind-set, strategy Time for engaging in research on sustainable alternatives	Awareness of sustainable/recyclable materials and production techniques Awareness of sorting and recycling limitations No communication with either sorting or recycling
Material	Product complexity	Material availability

3.2 Sorting

The heterogeneity of textile waste (including the vast amount of different blends) and product complexity pose the fundamental problems when sorting for recycling. These issues could be tackled at the design phase, but it seems that designers do not consider the end-of-life stage in their product designs (aligned with Lawless & Medvedev, 2016), as described by the sorting expert.

> Basically, designers can give us plenty of headaches – without being aware of it, of course. Putting too many blends or too many materials into one blend. Using a specific finishing or colours or … There are a lot of things that can go wrong, so to speak, or make things difficult for us.

Manual sorting is currently the primary sorting method, and it is based on an evaluation of textile reusability and recyclability just by looking and feeling. In the interviews, the method was considered problematic in terms of sorting efficiency and accuracy, and was hence linked to the economic viability of sorting businesses (also in Elander & Ljungkvist, 2016; Wedin et al., 2017). Automation was considered a future solution for accurate fibre identification. Yet, it was not seen to replace manual sorting, as that will still be needed to identify the reusable from the recyclable. Instead, automatic sorting was envisioned as being useful alongside manual sorting when aiming for specific fractions, especially for chemical recycling. Despite the rapid developments in automatic sorting, the challenge is that these technologies are as yet not ready to be applied at the industrial scale.

Sorting businesses focus on re-wearable (reusable) textiles. Regarding the external challenges, the interviewed experts reported that the quality of collected textiles is constantly decreasing due to fast fashion, and as such these textiles are less and less suitable for resale (aligned with Ljungkvist et al., 2018). Low-quality textiles are not suitable for mechanical recycling either if aiming for high-quality recycled textiles (fibre length is an issue). Chemical recycling, however, can provide means to benefit economically from these non-re-wearable fractions of low fibre quality, but those technologies also remain at the pilot scale.

Table 3. Challenges from the perspective of sorting

	Internal challenges for sorting	External challenges affecting sorting
Knowledge	Knowing by feeling	Awareness of chemical recycling limitations No communication with design
Material		Heterogeneity of textile waste Low quality of collected material Product complexity
Technology	Automatic sorting at the pilot scale Sorting efficiency (manual) Sorting accuracy	Chemical recycling at the pilot scale

3.3 Recycling

Also from a recycling perspective, product complexity and the heterogeneity of textile waste pose a major challenge for closed-loop recycling. As described by one recycling expert, most clothes are blends of many different materials and cannot be recycled without first separating them, which in many cases is not yet possible. In addition, depending on the recycling technology, different impurities may complicate material processability, i.e. certain fibres and chemicals can be critical for chemical recycling process X but not for process Y. Furthermore, even if the recyclers know the exact fibre composition, impurities like specific dyes or finishes (often mixes of several chemicals) may not be identified, causing unexpected problems in the chemical recycling process. Accurate information is required but it is currently impossible to obtain due to long supply chains. From the recycling perspective, the sorting phase plays a key role in closing the material loop. Aligned with the sorting perspective, automation is considered a necessary future development, as manual sorting cannot currently provide the efficiency and accuracy that would be needed.

The internal challenges mentioned by the experts relate to the current state of technologies. As chemical recycling technologies remain in their early stages (lab or pilot), recycling experts agree it is too early to give specific guidelines to designers and sorters; for instance, the tolerance levels of different fibres, dyes, colours and other components will first need to be studied on a case by case basis until certain patterns can be found and requirements can be generalised.

Table 4. Challenges from the perspective of recycling

	Internal challenges for recycling	External challenges affecting recycling
Knowledge	Limitations of recycling processes need to be studied case by case	Long supply chains Accuracy of material composition Products from the past
Material	Requirements for material input vary between technologies	Heterogeneity of textile waste Product complexity Sorting accuracy
Technology	Chemical recycling at pilot scale Separation of different fibres	Automatic sorting at pilot scale Sorting efficiency (manual)

3.4 Recommendations

The external challenges prompted numerous recommendations and requirements for means of improving closed-loop textile recycling. These details bring us one step closer to the original research question: the designer's role and practice in relation to textile recyclability. The experts' recommendations are summarised in Table 5.

From the design perspective, staff specialised in sustainable practices and product development within a clothing company was considered essential for support due to designers' limited capacity and time (also noted by the sorting expert.) Educating consumers

to appreciate recycled and recyclable products was also found critical. Otherwise design for recycling may not be worth the effort.

From the sorting perspective, design for longevity should be required prior to 'design for recycling', in line with the waste hierarchy. As the experts mentioned, quality could be decided on in the design stage. Moreover, sorters would appreciate garments of a single material. However, it was acknowledged that purely mono-material designs may not be a realistic way to go either. Instead, learning about each other's' processes was regarded as beneficial in understanding what sorting can and cannot do, thereby assisting designers to make appropriate decisions.

Next to designers, sorters also require up-to-date information on the newest technological advancements such as chemical recycling. The questions below clarify the requirements of the sorters:

> How specifically do you need to know the material [composition]? Is it enough to know that it's a blend? Or do you need to know that it's 70% polyester and 30% cotton? Or do you need to know what the elastane content is inside?

Both recycling and sorting businesses would benefit from digitalisation. An accurate tracking or tagging system for future products was mentioned as a requirement for transparency. In addition to knowing the fibre composition, it would be critical to identify the product per se, as that would allow tracking throughout the supply chain. It would be necessary to agree on a single coding system usable by every industry actor:

> Either companies work with their own closed take-back systems or then the system needs to be global.

From the recycling perspective, textile waste materials should be standardised. That would not only enable large enough volumes but also provide flexibility for sorters. Certain quality classes would help to standardise the technological processes of each recycler. The standardisation should start at the level of clothing businesses, i.e. based on their requirements, as one expert suggested.

While waiting for more information on recycling limitations, designers must settle with using very generic guidelines that align with multiple studies (Goldsworthy, 2012; Hasling & Ræbild 2017; Karell, 2018; Global Fashion Agenda, 2018b): Avoid elastane, laminations and polyurethane prints, use only a single material (mono-material design), and design modular product structures that allow separation of different materials. As described by a recycling expert:

> Mono-material is always the easiest. If you have one material and maybe one colour and one spin finish and you even know what it is, then it's easy. And you can really optimise the process such that you can recycle this.

In sum, the fundamental rule applies: The better recyclers know what the waste material feedstock contains, the better they can process it. This applies to both mechanical and chemical recycling.

Table 5. Requirements and recommendations of design, sorting and recycling for closed-loop textile recycling

Requirements & recommendations	Design perspective	Sorting perspective	Recycling perspective
Designer's role			
Active questioner, proposer	x	x	
Specialised staff for sustainability (and recyclability)	x	x	
Product design			
Avoid elastane		x	x
Avoid lamination		x	x
Avoid polyurethane prints		x	x
Design for modularity		x	x
Mono-material design		x	x
Simple structures		x	x
Technology			
Automation of sorting		x	x
Industry-wide identification (tracking) system		x	x
Knowledge			
Crucial role of research projects	x	x	x
Educating consumers to appreciate recyclability	x	x	
Education on 'design for recycling'	x	x	x
Up-to-date information (materials, technologies)	x	x	x
Material input			
Pure fractions			x
Quality standards for recyclable materials			x
Mindset			
Common commitment	x	x	x
Legislation	x		x

In addition to field-specific recommendations, the interviewed experts also shared the following views: Research projects were considered vital in shaping the general mind-set and sharing knowledge while trying to solve challenges together. Shared commitment and goodwill in tandem with incentives driven by legislation were equally emphasised. Experts also shared the view that 'design for recycling' should be part of design education. Likewise, up-to-date information on recyclable materials and technological advancements was mentioned as a necessity. As the interviewed designer described, knowledge of different limitations is fundamental in order to generate 'the right kinds of ideas' in product development. The information should be available (and constantly updated) for designers working in the industry. A digital platform based on open access and peer review – 'Wiki of

Textiles' – was envisioned as a solution for efficiently sharing information on recyclable materials, novel techniques and advancements in recycling technologies.

4. Discussion

The findings provided us with multiple details that help to understand clothing designers' practice when aiming to design for recycling. The research shows the designers' dependency on multiple actors in the supply chain. The external and internal challenges identified above clarify designers' limited ability to make decisions that would support closed-loop textile recycling. Yet, if aiming to meet the previously mentioned sustainability goals, it is clear that the traditional design process (in a linear system) – and the role(s) of designers within it – would need to expand. Here, we come to answer our main research question and highlight the following implications of the 'design for recycling' approach for the clothing designer's role and practice: 1) New strategy, 2) new knowledge & new circles, 3) new challenges.

4.1 New Strategy

As part of the 'design for recycling' approach, designers must first consider product sort-ability, as that is the link between the design and recycling phases. Even though sorting and recycling face similar challenges when it comes to material input, they also have their very specific process-related issues. If textile waste material cannot be reliably identified in the sorting phase, it is not possible to direct the material to appropriate recycling processes. Certain material blends as well as product structures (e.g. multilayer products) can distort an automated sorting process and cause unexpected contamination later in the recycling phase. Hence, we propose 'design for sorting' as a separate strategy from 'design for recycling'. We do this to clarify that what might be process-able for recycling, might not be possible to identify by the sorters, and vice versa. In addition, because recycling processes differ from each other, it is not very likely that designers could design for a specific recycling stream (unless the business has its own closed system), whereas sorting processes seem to be more similar to each other – at least currently.

4.2 New Knowledge & New Circles

Successful 'design for recycling' calls for an active and open dialogue between design, sorting and recycling, especially in terms of the emerging technologies, their current limitations, possibilities and newest developments. In practice, it means extending the designers' knowledge of the processes and practices beyond their own – a challenge for future education. First, designers need a general understanding of automated textile sorting technology and its limitations in order to design garments that are firstly suitable for sorting – and secondly for recycling. Thereafter, deeper material knowledge in relation to different recycling methods is required, i.e. knowledge of material recyclability.

Up-to-date information is currently scattered and difficult to find, as automated sorting and chemical recycling processes are still emerging. Within the industry, practicing designers could take greater initiative, starting direct conversations with the sorters and recyclers by

asking about the different process requirements – very similar to how they (their teams) query material properties from material manufacturers. Yet, generic information about the bottlenecks in both sorting and recycling should be easily accessible and, as research advances, should be used to expand the understanding of certain process requirements. Digitalisation could assist in the quest for openness. Whether as a 'Wiki of Textiles' or in some other form, new collaborative and digital circles should be established – that is, circles where information is openly shared to assist decision making in the design process. Such a platform could allow co-production of the essential knowledge (the best practices) on a larger scale. Certain initiatives (like the ones mentioned earlier) could take a leading role here. Designers on the other hand would be needed to point out the limitations of their knowledge and demands. What is the information they require? What kind of support would they need? Similar questions should be asked from the sorters and recyclers as well.

Figure 2 visualises the knowledge flows required between design, sorting and recycling. For example, sorters need specific requirements, i.e. tolerance for different impurities, from recycling companies in order to deliver accurate textile fractions. With this figure, we also aim to underline design's dependency on sorting and recycling, even though they may appear to be distant stakeholder groups considering the long textile supply chain.

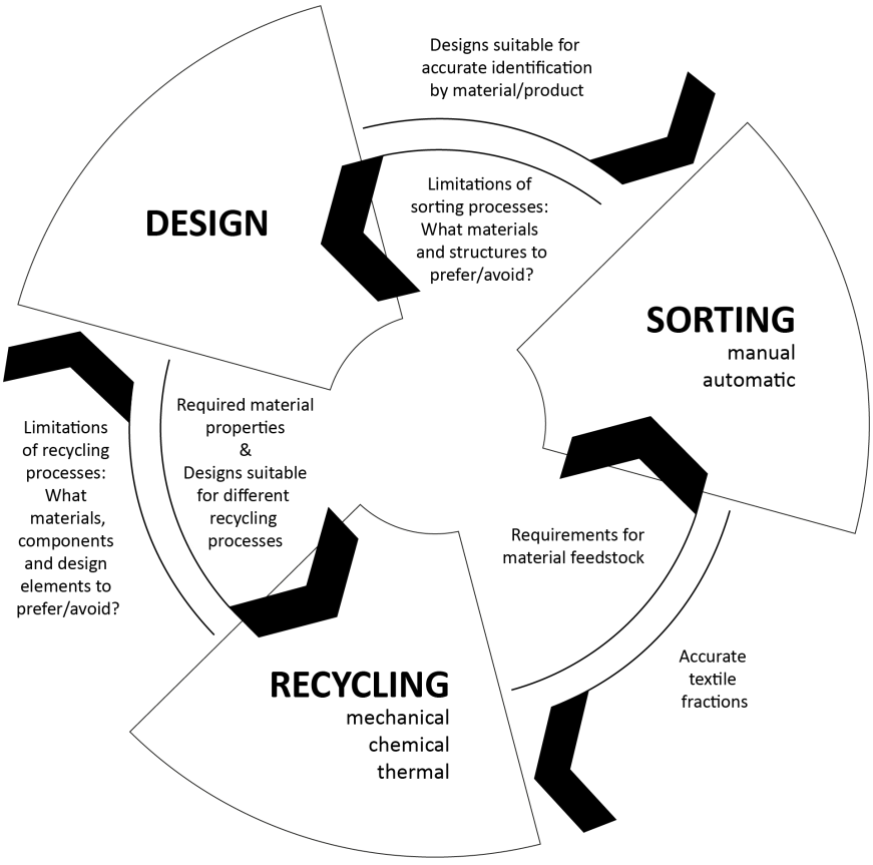

Figure 2. Visualisation of knowledge flows required between design, sorting and recycling.

The active collaboration pictured above could lay the ground for constantly evolving open design guidelines that could facilitate the identification of the priority order of design decisions. Guidelines in relation to product complexity (use of specific textile fibres, their blends as well as material and product structures) would be ideal to assist designers to first evaluate the product-sort-ability, then recyclability. Limitations in the chemical recycling of textile materials could lay the ground for further guidelines. When the limitations of sorting and recycling are known, it helps design teams to source alternative (recyclable) materials for their products. For instance, if designers are made aware that elastane material or polyurethane prints harm recycling processes, they can start to source and request alternatives from suppliers accordingly.

4.3 New Challenges

Aiming to increase closed-loop textile recycling implies a new set of challenges for designers. 'Design for recycling' imposes limits on material options (blends and material combinations), product structures, decorative details (e.g. prints), functional details (buttons, strings, bands, etc.) and functional finishes. As technologies and knowledge evolve, the use of certain fibres, blends and details might even be forbidden. If so, companies would have no choice but to follow the regulations. Limiting the number of design choices – potentially resulting in more simple designs – asks for a great deal of creativity and a problem-solving attitude from designers. How can designers ensure that products remain interesting and relevant in the eyes of consumers *if* they give up certain aesthetics or functionalities (e.g. elastane in sportswear)? Bigger companies certainly have the resources to research and develop new alternatives if needed, but what about the smaller companies?

4.4 Limitations of the study

The paper provides only a narrow snapshot of the current issues in textile circularity, from the perspective of design, sorting and recycling experts. Perspectives of users and manufacturers were left out of the study due to its specific focus, which can be argued to be a limitation when addressing systemic challenges. Generalisations cannot be derived from the findings. Even though the study is limited in terms of the number of interviewees and different views, the findings provide support for previous studies and widen the ongoing discussion, creating a basis for future research.

The authors of this paper do not take the circular economy approach as a given, even though the study neglects its critics. Even if the circular economy concept has been integrated in political agendas globally (e.g. in the European Union and China), its potential in terms of social sustainability, and its dependency on economic growth is debated, and hence would require a more critical approach – which is absent in this paper.

4.5 Future research

Deconstruction of commercial fashion design processes, i.e. an investigation on what is actually happening during the design process in clothing companies, would be important in order to understand how 'design for recycling' could be integrated into their creative

processes. We know that the practice must change, but how this change should be carried out is dependent on the companies' practices. Action research or other research interventions within fashion companies would be required.

Further research on the limitations of automated sorting and textile recycling processes is also needed in order to create more specific guidelines for designers. This means systematically following the developments in sorting and recycling technologies based on various sources in order to gain a deeper understanding of the challenges and what they actually mean for designers. Only then will it be possible to 'translate' the challenges into guidelines that designers can easily follow.

5. Conclusions

This study set out to contribute to a better understanding of the designer's role in relation to closed-loop textile recycling, with whom they should collaborate, and how they could do so. Multiple challenges aligned with earlier research were identified, in tandem with recommendations to overcome them. Active collaboration with textile sorting and recycling was argued to be necessary in future development efforts. Currently, the dialogue between these stakeholders is weak, posing a substantial barrier to textile circularity, especially recycling. Without knowing the limitations and recommendations of sorters and recyclers, designers remain unaware of which materials and what kinds of product and textile structures to prefer or avoid when targeting recyclable garments. Sorting and recycling technologies are advancing rapidly. Hence, ongoing dialogue on the latest requirements of these processes (in tandem with novel material developments and production techniques) is essential to easily consider the sort-ability and recyclability of garments at the design phase. Within the corporate environment, designers can question the practices and suggest novel approaches, but as long as there are no explicit and updated design guidelines (how to design for sorting and recycling), the efforts to produce circular designs are hindered by time and knowledge constraints, allowing the linear fashion system to continue and expand.

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