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MIXING IT UP IN PRATO: identifying innovation hotspots within mechanical textile recycling

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Abstract

Purpose:

The aim of this research paper is to provide new insights from the Prato recycling model for woollen materials. Specifically, to examine the barriers presented but also opportunities that wool recycling might offer for future innovation within mixed fibre textile recycling.

Originality/value:

This paper examines the established Prato model from an alternative angle considering the mechanical textile recycling system alone. Considering the industry from this viewpoint has created value-added insights for design innovation for mixed fibre recycling of the future.

Design/methodology/approach:

Two visits to the city of Prato, Italy was undertaken to generate data collection. Using a field research approach, observed through the eyes of the designer, through unstructured interviews and documentation (note taking and photographing). Data was analysed using annotated portfolio techniques to draw out insights from the observations made during the visits. Finally, a hotspot analysis method was used to formalise insights as key areas for future action.

Findings:

The findings in this paper demonstrate an overview of the Prato model of competitive collaboration within the textile recycling industry. Furthermore, it establishes the barriers to and opportunities presented by the mechanical recycling of wool/cashmere in Prato. These were consolidated by outlining four key hotspots within the recycling system: sorting, blending, processing and end-product/market. These hotspots are proposed as a call for future design innovation and research towards mixed fibre recycling and circular fibres of the future.

Keywords: Sustainable fashion/textile industry, mechanical recycling, wool, Prato Italy, Mixed Fibre

Article Classification

Research paper

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1 Introduction

The fashion/textile industry is causing catastrophic environmental impacts throughout all lifecycle stages (Fletcher and Grose, 2012), in particular at the end-of-life where less than 1% of our waste clothing is recycled back textile-to-textile (EMF, 2017). However, the industry's consistent use of blended yarns, increasingly desired for their function and price benefits (Turley *et al.*, 2009), and the resultant mixed fibres are problematic for developments in new technology, both chemical and traditional mechanical recycling (Mathews, 2015).

Over the last decade advancements in the field of textile recycling have evolved, yet mechanical recycling has been overlooked as calls for investment refer to chemical processes alone (Dahlbo *et al.*, 2016). The challenge now is how solutions to this growing issue can impact the industry at both a local and global level. Understanding the barriers to textile recycling can support the next generation in how we educate, train and employ this sector.

This paper explores the historic and current situation for mechanical textile recycling within the wool industry in Prato, Italy. Understanding the development, both positive and negative, of Prato's historic industrial model (Ottati, 2009) forms the backdrop for insights around innovation. Using a field research methodology (Burgess, 1982) the author visited a small selection of wool/cashmere recycling facilities with the aim of understanding their current and varying approaches. Through conversation, first-hand experience and designerly ways of exploring these industrial processes (Cross, 2007) data was generated for analysis.

The insights from this paper seek to demonstrate some of the principal opportunities and barriers faced by the textile recycling industry for wool, and in turn how this might affect the more challenging mixed fibre recycling. Furthermore, by creating an overview of the recycling system in Prato, this enabled the author to identify key 'hotspots' (Barthel *et al.*, 2015) for future potential innovation. This paper explores insights towards creating circular fibres (EMF, 2017) of the future within mechanical textile recycling.

2 Context

The continuing rise in global resource consumption has instigated a growing trend for increased fibre production. This gross over consumption of fibre and has caused a ripple effect of excessive textile waste in the global fashion industry (Mathews, 2015). This waste is increasingly low in quality, unable to be reused as clothing and holds little or depleted value as it filters into limited end markets (Dutch Clothing Mountain, 2017). Textile waste in this context is either 'post-consumer' or 'pre-consumer'. The former is defined here as any waste textiles including garments that have been used by the consumer, while the latter refers to the type of waste that does not reach the consumer such as factory waste clippings (Hawley, 2006).

The lack of textile to textile recycling globally can be attributed to a lack of technology and end market potential. However, it has been suggested with the right technologies and infrastructure recycling could increase to be in line with current rates of collection (Fibresort, 2017).

One of the biggest challenges for recycling technology today is the industry’s consistent use of blended materials, used for their resultant functional properties and price benefits. Currently, there is limited research investigating the composition of our textile waste. Still, current available data gives us some understanding of the problem. A recent UK based exploration of clothing collected by The Salvation Army found that 36% of its sample was made up of two or more fibre components (Ward, Hewitt and Russell, 2013). This was supported by Dutch Clothing Mountain's 2017 report which generated similar data, finding 37% of their sample was blended textiles. Furthermore, this percentage could increase as 30% of the clothing were unidentifiable due to missing labels. Although both studies demonstrate mono-fibre textiles occupying the majority, blended textiles are still a growing issue that needs to be addressed. Finding a solution for waste mixed fibre textiles is prevalent as they continue to be problematic for both chemical and mechanical recycling technology.

2.1 Historical Context

Prato’s historic textile industry dates back to the middle ages and today every stage of textile manufacture can be seen around the city (Mondadori, 2013, p. 14). The origins of wool recycling - or more specifically the invention of machinery to tear fibres from cloth – are attributed to Benjamin Law in Yorkshire, England in 1813 (Shell, 2014). These tearing machines, now known as pulling machines, appeared in Prato in 1850. Later carbonizing machines emerged, to separate wool from cotton fibres, meaning that Prato could be competitive with the northern Italian wool industries. By 1870 a centralised factory-based system had been introduced. This allowed for the development of mechanised wool carding and spinning, and enabled Prato to become an exclusive and specialised centre. Prato’s carding method, allowing shorter wool fibres to be spun (virgin or reprocessed), is what distinguishes its famous woollen cloth (Museo del tessuto Edizioni, 2007).

During the first half of the twentieth century low-medium quality regenerated wools and carded fabrics were in high demand until the textiles industry was forced to adapt to post-war conditions. Larger factories struggled without the military textile demand and were dismantled to create smaller family-run enterprises and craft workshops, building a flexible industrial structure. At the same time, new synthetic materials were entering the market offering functional and cost-effective competition. Fast adaption saw Prato blending synthetics with regenerated wool to retain competitive business (Museo del tessuto Edizioni, 2007). Despite this, Prato remained famous for its carded woollen product, until the 'carded wool crisis' in the late eighties. This caused many factories to drop their traditional carded lines for higher quality worsted spinning, a technique which uses long virgin fibres for couture production. The trend for worsted fabrics has continued, fighting off competition from developing countries. Today, the mark of quality woollen product is synonymous with the 'made in Italy' label (Weibel-Orlando, 2012). Yet, as the success of worsted cloth has grown, the traditional carded manufacture has continued to fall into decline (Ottati, 2009).

2.2 Prato Model

The 'Prato Model', according to Magi and Ceccarelli (2002), is completely unique in that it is comprised of many small and medium enterprises. It is for this reason, Padovani (2017) asserts, that the model is based upon value added partnerships.

> The Prato system is based on the decentralization of production among a large number of small companies capable of adapting to specific design demands and able to produce short runs to tight delivery times. This model of collaborative competition provided the basis for the rise of luxury and bespoke manufacturing (Padovani, 2017, p. 144)

In addition, the industry's deep-rooted history over a changing landscape has produced an expert tacit knowledge. This has led to an 'innovation pipeline' between traditional processes and new products. It is the combination of the Prato model and the expertise of the industry that has allowed it to dominate the regenerated wool market (Padovani, 2017). However, as Ottati (2009) points out the Prato industry is in potential crisis with two contrasting views considered. Either Prato's successes lie in the past or it will be able to adapt to a future of globalisation.

More recently, the industry has joined forces, assisted by Prato Centre of Commerce, to promote the growing consumer interest in sustainability (Testa *et al.*, 2017). The creation of the 'Cardato Recycled' brand was created to boost the declining carded wool industry by creating a certification and unique selling point of the recycled cloth. There are strict requisites for any brands to display the 'Cardato Recycled' label. The materials must be made of at least 65% recycled content (clothing or factory waste), must be produced in the Prato district and brands must measure the environmental impacts of production (water, energy and CO^2 Levels) (Cardato, 2018).

3 Methods

The methodology undertaken for this research paper brings together a variety of data collection and analysis methods in its qualitative approach. Using traditional field research methods such as observation, unstructured interviews and documentary evidencing (Burgess, 1982) with 'designerly ways of knowing' (Cross, 2007) and tacit knowledge (Polanyi, 1958) has enabled data to be collected. Combined with a variety of analysis techniques such as annotated portfolio (Gaver and Bowers, 2012) and hotspot analysis (Barthel *et al.*, 2015) this facilitated the author to extract insights from Prato's wool recycling industry towards future increased mixed fibre textile recycling.

Across two field visits to the city of Prato four key factories, Companies A-D (see Table 1), were selected as a sample to provide a balanced framing of the developed wool recycling industry. This was supplemented by three additional companies E-G (see Table 2), affording a broader understanding of the opportunities and barriers within the field. While A-D were researched in far greater depth, Companies E-G provided additional insights that contributed significantly to the overall findings.

Observed through the eyes of the designer this method provided a foundation for future innovation in design (Suri, 2005). The author's tacit knowledge from working previously as a commercial knitwear designer ensured understanding of both the commercial and practical process. The importance of a second visit allowed the author to build relationships with experts, gain extended first-hand experience, and ensure thorough data collection meaning industrial processes, systems design, and recycling design practices could be fully explored. Consent for visits and was obtained from each participating company with the agreement that their details would be anonymised.

Analysis was primarily achieved using an annotated portfolio method (Gaver and Bowers, 2012, Sauerwein, Bakker and Balkenende, 2018) using photographs taken throughout the experience. This was accomplished by using the collected field notes, and memories of the experience to annotate the images. These annotations were organised into themes across all the factory visits and formalised into simplified tables (see below Table 1 and 2).

By building upon previously established recycling systems diagrams by WRAP (2012), meant visualising the specific processes for the wool recycling systems in Prato. Hotspot analysis was applied to bridge the gap between Prato insights and the wider textile recycling system. This method provided a more comprehensive understanding of impacts and therefore a prioritisation of future actions (Barthel *et al.*, 2015), which in this paper applies to complex mixed fibre recycling.

4 Discussion

The aim of this research paper was to establish key areas for innovation within mechanical recycling processes. The objectives included gaining an understanding of the Prato model and the industry's array of processes, then from this ascertain barriers and opportunities in wool recycling to offer innovations within mixed fibre textile recycling.

4.1 Diversities

As shown in Table 1, Companies A – D were selected for their individual approaches and to create a balanced framing. A variety of final products were seen to be produced: fibre, yarn, fabric or a combination, all of which ranged from high to lower market values. The balance of the sample range is further demonstrated by the assortment of ‘input’ or ‘feedstock’ and output materials across woven/knit, pre/post-consumer and mono/blended.

		COMPANY A	COMPANY B	COMPANY C	COMPANY D
END PRODUCT PERCEIVED QUALITY		HIGH	HIGH	HIGH/MEDIUM	MEDIUM/LOW
FIBRE TYPE - INPUT		CASHMERE	WOOL	WOOL	WOOL / WOOL BLEND
FIBRE TYPE - OUTPUT		CASHMERE / CASHMERE BLENDS	WOOL BLEND	WOOL	WOOL BLEND
END PRODUCT		YARN / FIBRE / KNITTED PRODUCT	WOVEN FABRIC	FIBRE ONLY	YARN
WASTE TYPE		KNIT	WOVEN	KNIT	KNIT / WOVEN
END MARKET		KNIT	WOVEN	WOVEN	WOVEN
WASTE: POST CONSUMER		X	X	X	X
WASTE: PRE CONSUMER			X (SMALL %)		X
OUTPUT YARN	MONO	X			
	BLEND	X	X	X (ONCE SOLD)	X

Table 1. *Simplified recycling system insights from companies A-D,* Source: Author

All stages in mechanical wool recycling (see Figure 1 below) were seen first-hand in the field. Through conducting this research not only the procedure, but the decisions and requirements at every stage, were clearly identified. This enabled the author to understand how these choices impacted future processes and final products. It was this overview which enabled insights for future design innovation.

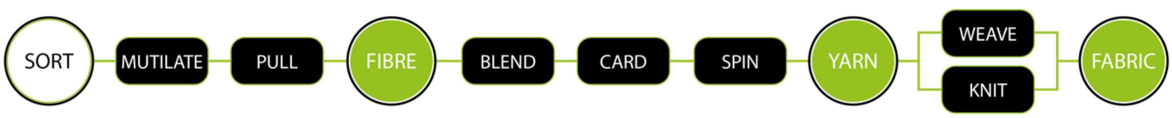

Figure 1. Simplified processes of recycling textiles, adapted from WRAP (2012), Source: Author

4.2 Collaboration

As previously described by Padovani (2017), the Prato model has been built from decentralisation and competitive collaboration. One of the main reasons the industry has been able to adapt. During the field visits the author witnessed how Companies D and E used the same processing facility to transform fibre to yarn by giving a tour of the same workshop. This partnership between the two businesses had developed between the owners which was later found to be based on a deeper friendship established over generations.

	COMPANY E	COMPANY F	COMPANY G
END PRODUCT	YARN/FABRIC	FABRIC	YARN
RECYCLED FIBRE	WOOL	WOOL	COTTON / WOOL
PRODUCTION	ON SITE	OFF SITE	OFF SITE

Table 2. *Simplified recycling system insights from companies E-G*, Source: Author

Quickly, it was recognised that all companies in the sample had close relationships with the other businesses, although not always as deep rooted as the previous example. Much like a small village, everyone knew everybody else. Each company had their own segment of the recycled wool market. Company C, for example, specialised in sorting knitted post-consumer waste which was outsourced to be pulled into fibre and returned for quality control. The final product, the fibre, could then be sold for processing into yarn.

In contrast, Company A demonstrated collaboration in reverse, 'insourcing' rather than outsourcing. By allowing second hand traders access to the incoming bales of cashmere (before colour sorting) they were able to search for the 'diamonds'. Diamonds referred to here comes from Hawley's (2006) categorisation of textile waste sorting, considered to be rare finds, often designer items of high value to the vintage or second-hand market. It is this interconnected competitive collaboration amongst smaller specialist companies which has allowed the Prato model to flourish.

4.3 Sorting

The sorting process embedded within the recycling system stretches far beyond the selecting of 'diamonds'. Companies A-D all emphasised the importance of sorting on the quality of the end material. However, it was recognised that sometimes companies bought in pre-sorted clothing waste, processed in special economic zones such as India, connecting Prato to the global recycling industry. Nevertheless, others prided themselves on training specialist employees who sorted mixed bales by colour and shade. Company C took this one stage further separating shades into 'ordinary' (chunky guage knits) and 'fine' (fine guage knits) to produce, as they claimed, a higher quality resultant fibre.

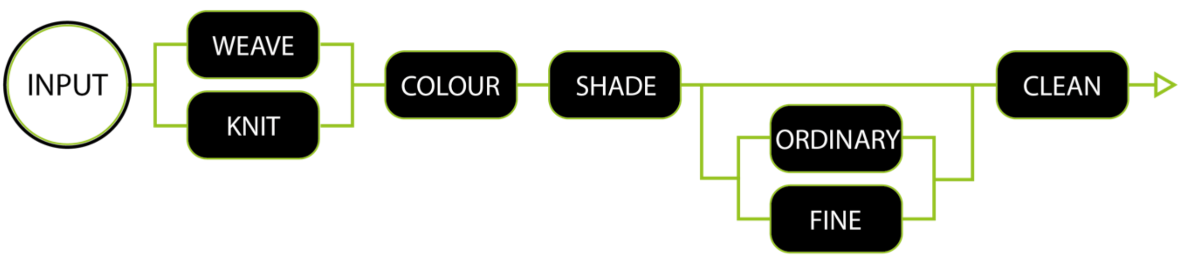

Figure 2. Simplified processes of sorting waste textiles, Source: Author

The sorting stage is one of the most costly processes within textile recycling. Although this hand process was a unique selling point for companies such as B, it was accepted that this labour-intensive method in a high wage country strained the industry economically. Nonetheless, one of the largest barriers to successful recycling is colour contamination, the result of inefficient sorting. Contamination itself presents in the form of ‘neps’; contrasting coloured specs which stand out and, in some cases, protrude from the yarn or fabric surface. This could be exploited as a design feature, often requested by designers for fashion clothing. However, it is still problematic when a mono-colour is required. It was understood that mechanically recycled yarns can never be completely solid. Time and effort is often taken creating melange effects from virgin materials, which without any effort is a natural quality of recycled yarn that ought to be taken advantage of. However, stock colour cards exhibited a wide range of colours in melange as well as close to sold shades (Figure 3).

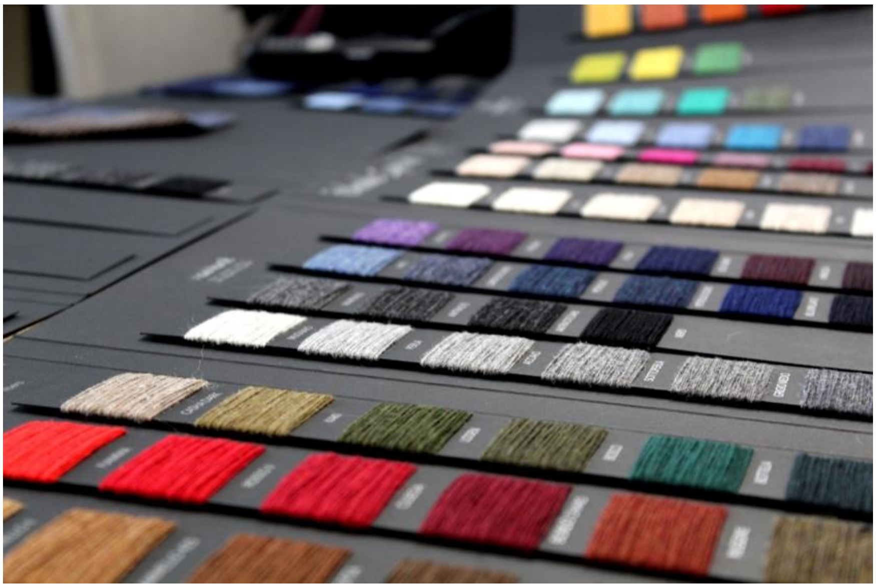

Figure 3. Company B stock colour cards, Source: Author

4.4 Overdyeing

Due to the nature of the process, single colour materials were valued over multi-colour items. While generally avoided, all companies used overdyeing as a solution for these multi-coloured materials. Company D did this to tonal patterned garments to create uniform shades, whereas true multi-colours could only be dyed black to ensure complete coverage. Another reason to overdye was to obtain a specific colour shade which otherwise could not be produced. The availability of feedstock was proved to be fundamental in producing a material’s final colour. If a client required a specific shade, a combination of coloured fibre would be blended to produce its exact colour, as seen in Figure 4.

However, if one element of a colour blend is not readily available, overdyeing a similar shade provides a solution to deliver the overall blend.

Figure 4. Company B shade blending for client colour development, Source: Author

4.5 Input and Output

Across companies A-D perceived quality of feedstock materials was found to be reflected in the quality of output material. This follows that the purer the fibre to be recycled, the higher quality it is considered to have i.e. mono materiality. The Prato recycling system is therefore centred around sorting and finding the highest quality fibre for recycling, in this case wool. Even Company D, whose input material was lower value wool blended product, was sorted according to the quantity of wool content.

In contrast, as Table 1 demonstrates, across the four key companies, each used a different combination of input to output. A and C exclusively was found to use knitted waste, whereas B used woven waste. Contradicting information was supplied in terms of what feedstock produced the best quality result. This was attributed to the bias of each company to promote themselves. However, all companies agreed that knitted feedstocks were easier to pull, generating longer fibres. Yet this was not reflected in the authors analysis of the perceived quality of the end product. For example, Company B produced a quality product from a woven waste feedstock. The greatest insights in this area came from Company D who demonstrated that mixing a combination of woven, knitted, pre/post-consumer waste would balance out the qualities to create a mid-value end batch. The main attribute affecting the perceived quality of the material output was the percentage of the wool fibre.

A common misconception, one that was made by the author, is that Prato predominantly uses pre-consumer waste as a feedstock. It was found that pre-consumer wool recycling formed a small section of the overall industry. Although pre-consumer waste was utilised by other businesses, as clarified by C it was too expensive for them to warrant using. The only active example of pre-consumer waste recycling was company D. By mixing lower value post-consumer fibre with higher value pre-consumer meant the wool composition could be closely controlled for each batch.

4.6 Quality

The quality of fibres was a reoccurring theme throughout the visits. A concern presented by Company F were its customers complaints about the varying eveness and colour fastness of the recycled fabrics. Colour fastness was ascribed as a property passed forward from the previous garments, with little solutions available. However, the notion of garments passing on properties it not always attributed to the negative. Recycling in this way retains the colour from their previous lives utilised it in the new material.

One of the main processes that can promote quality is ‘cleaning’. This refers to the removal of buttons, zips, seams, and contrasting coloured trims. Although these are established practises of raising quality of recycled fibre, the removal of seams was a debated exception. Seam removal was dependant on the quality of the resultant fabric required by a customer. It would only be completed if the companies felt it would add value to the end product. As a labour intensive and costly exercise, economically it had to present value for money.

4.7 Blending

The quality of mechanically recycled fibre has been criticised laboriously by researchers and brands alike. It is well documented that recycling yarns in this way damages the fibres and reduces length (Gupta and Saggu, 2015, Yuksekkaya *et al.*, 2016). Blending offers a solution to this issue, one that has been used throughout history (Shell, 2014). This can be done for colour, composition, function and/or ascetics. For the new schools of thought centered around a circular economy blending has been rejected as the emphasis is placed on mono-materiality within a cradle to cradle model (Braungart and McDonough, 2002). That said, blending virgin fibres in the modern day is common place. It is widely established that for a circular economy; products, components, and materials must be maintained at their highest utility and value at all times (EMF, 2017). For mechanical recycling this means blending. Most prominently this was seen by virgin fibre being blended with recycled, although more innovative examples were revealed. Company A for example, would sell the ‘cleaned’ cashmere seam waste for blends. The seam waste would be approximately 95% cashmere composition therefore, it could be added into a virgin or recycled batch to achieve 10/20% cashmere blend. Whereas D’s blended woollen feedstock was utilised to produce a blended wool product not inappropriate for today's blend heavy market.

Recycled stock yarns were a common service provided by companies B and D. Any other blends were specially developed for individual clients, and therefore heavily dependent on the requirements for the end product or market. The design decisions throughout the process were crucial when reaching this stage. All six companies maintained the materials produced could be recycled again, yet there was no evidence this had been planned for within the system. This wasn't due to a lack of enthusiasm for sustainability, but restricted by the global market for buying Italian wool and the lack of any formalised take-back system.

A further concern is the incompatibility of the feedstock and resultant material. Company B for example, brought in high percentage wool input, accepting no lower than 97%. In contrast the output was a wool blend, with the richest wool stock service yarn reaching 75%. Meaning the output materials would be unacceptable if recaptured and could only be down-cycled.

4.8 End Markets

The need for developing end markets for recycled fibres has been found by Elander and Ljungkvist (2016) supported by the 2014 WRAP report as a residing issue across many areas of the textile recycling industry. This was echoed in Prato, as businesses felt pressure to continually increase the value of materials. This was demonstrated most prominently by Company A who was not only selling fibres, but yarns and garments too, and was also seeking to develop new end markets by producing products using traditional recycling methods. This included producing a needle felt for inside luxury quilted outerwear and using blended cashmere fibre to replace feather down, as an alternative for active-wear apparel.

5 Insights

5.1 Prato Recycling Model

The unique Prato model that has established within its woollen textile industry can be segmented to focus on recycling in which little research has been conducted exclusively. As a form of analysis, a simplified diagram modelling the connections and flow of materials was created (Figure 5).

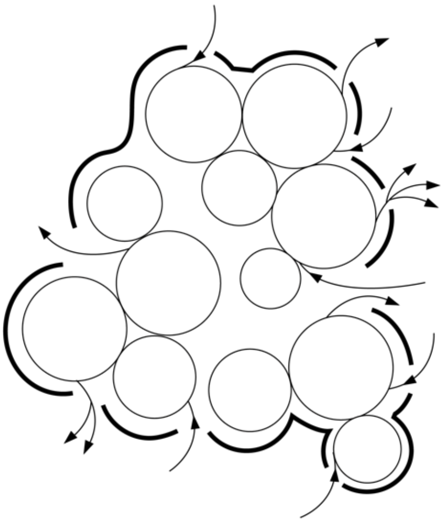

Figure 5. Simplified Model of Prato Wool Recycling Industry, Source: Author

The diagram uses circles representing single companies and signifying the life cycle of the materials or services they provide. The boundary of the Prato district is broken by incoming materials and outgoing products connecting this small segment to the global recycling industry. The circles meet as the small and medium sized facilities collaborate. In Figure 6 we can see in detail the example of companies D and E and how this worked in practice.

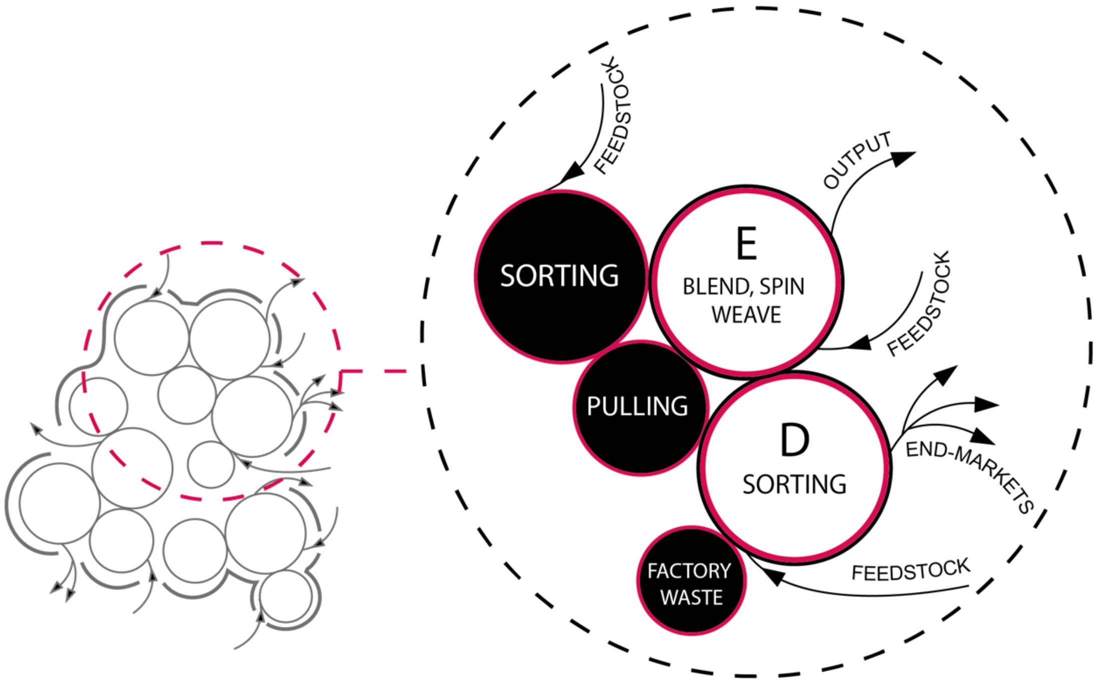

Figure 6. Detail of Prato wool recycling industry simplified model, Source: Author

This visualised system falls into the category of open loop recycling in which Payne (2015) points out materials are generally not reclaimed. The open loop system, which is fed from the global waste woollen apparel industry, is down-cycled often into blended woollen fabric that is not readily recycled again.

This model demonstrates how a small and specifically located industry is embedded and connected to global recycling as well as the virgin textile industry. The problem of material collection is one that spans these two industries, and is one of the biggest barriers that is faced. This is challenged in the most recent ECAP report suggesting collection can only be solved with a spectrum of methods collaboratively rather than competitively, much like the Prato model suggests but on a larger scale (Watson *et al.*, 2018).

5.2 *Barriers to the opportunities*

Understanding the barriers and in turn how these might be future opportunities for innovation witnessed in Prato was a first step. The Prato wool recycling model, visualised by the author in Figure 5 and 6 has enabled a simplified overview for a future systems approach which can be considered towards mixed fibre recycling. Understanding the underlying system in which the industry operates can aid design choices which are critical for innovation. Ripple effects could be seen from every decision along the process from the sorting to the end product, leading to the author plotting the key barriers and opportunities along the recycling process. This resulted in four areas being highlighted as impact hotspots (Barthel *et al.*, 2015) for future design intervention towards increased value of materials (see Figure 7).

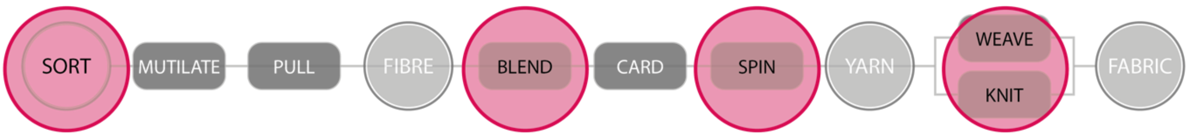

Figure 7. Hotspots for innovation within the processes of recycling textiles, Source: Author

5.2.1. Hotspot: Sort

The first hotspot area identified was the sorting stage. Current work on new technological innovation to replace manual sorting is being developed using NIR technology (Wedin *et al.*, 2017). This could provide a solution to the cost barriers prevalent in Prato, but as Wedin *et al.* (2017) points out does not solve the issue of sorting blends particularly with a low fibre content or multilayer garments. More specific to the issues in Prato was the inconsistent information regarding the quality of woven verses knitted materials to the process. These are therefore potential areas for the further design research.

A key opportunity within the sorting stage was the sorting by primary fibre. For Prato this was wool. Even when recycling blended fibres, the materials were categorised by the amount of wool content. Wool in this case was the most desirable, due to the fact it was being processed within a wool industry. From this we might infer that for mixed fibre sorting, categorising using a 'primary fibre' could aid the process. This insight demonstrates the need to understand the material composition, which currently is skilled and labour intensive, to aid sorting technology for new types of 'primary fibre' categories which should flow into specific end markets.

5.2.2. Hotspot: Blend

The feedstock of any recycling process is one of the most important factors, but is still heavily reliant on the types and colours of materials coming into the system. As previously discussed overdyeing is used when there is limited availability of coloured feedstock for shade blending. The challenge of varying feedstocks is a targeted area for innovation exploiting areas of opportunity such as melange effect of recycled yarns.

Blending is often associated with negative connotations when concerning the circular economy. However, for mechanical textile recycling, blending represents a positive by increasing quality and often creates a cost-effective end product. Notably there is a lack of research comparing woven verses knitted feedstocks and the effects of combining these different inputs of waste. It is a challenge to find new ways of increasing quality at the blending stage, as well as utilising different forms of blended materials to produce appropriate products for end markets.

5.2.3. Hotspot: Processing

Processing, or spinning most prominently used in Prato, is one of the more technical areas for innovation. Yet, this could provide a significant space for intervention. Spinning yarn for weaving or knitting is only one way of processing fibres. Looking to more traditional methods to produce alternative products is an opportunity. For this approach to work there needs to be full system understanding, connecting this hotspot to the other processes and developing new ideas towards circular and recyclable products of the future.

5.2.4. Hotspot: End Product/Market

Developing recycled alternatives for the needs of the textile manufacturers, currently using virgin and often blended materials, is a challenge across the industry. This reiterates the importance of understanding recycling feedstocks as a fundamental way to design and develop desirable materials. This knowledge can then be used to exploit advantages and seek solutions for properties that are passed on from feedstock to output and plan for this in the design process for suitable end markets.

5.3 Limitations

The scope of this research could be limiting due to using a small sample used as a form of analysis of an entire industry. Owing to the time scale available only two visits to Prato were undertaken, meaning the sample size was selected from the companies willing and available. Subsequently, this affected the number of observations that could be completed. However, to achieve the research aims the time allocated was accepted to enable thorough analysis and meaningful insights. When reflecting on the learnings from a single small area to seek solutions for mixed fibre recycling it is important to remember that textile recycling is a global industry. Therefore, further research into other textile recycling sectors might be considered to form more comprehensive deductions.

6 Conclusion

The field research undertaken was a means to develop designerly understanding of the wool recycling industry in Prato. The insights unearthed were a method to seek further solutions for the more problematic mixed fibre textile recycling urgently needed in today's wasteful fashion industry.

By completing this, a deeper understanding of the processes within the wool recycling industry have been yielded. Furthermore, by reflecting on the barriers and opportunities and translating these insights towards mixed fibre recycling, key hotspots for innovation have been uncovered. Understanding the value of the hotspots can signpost further research to create material and systemic interventions within mechanical textile recycling to create circular fibres of the future.

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