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Investigating knitwear product development in small and medium enterprises: A report of practices related to environmental sustainability

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ABSTRACT

There is rising interest into the inner workings of the fashion supply chain due to increasing concern surrounding environmental impact, social responsibility, and economic growth. Studies designed to understand the fashion industry often presume the knitwear sector to follow the linear product development process of the woven garment sector. However, knitwear practitioners are profoundly aware of many complex distinctions, one example being the ability to seamlessly create three dimensional garments with minimal finishing. In spite of these differences, there is little known research which specifically identifies the current knitwear design and manufacture system, or how often such seamless production methods are utilised. To bridge the gap in knowledge, a quantitative questionnaire was designed for a holistic overview of the key product development processes within knitwear small and medium enterprises (SMEs). The questionnaire had three focuses, design, manufacture, and retail, reflecting the sectors dynamism. 31 companies of varying sizes completed the survey, of these, 26 designed knitwear, 25 manufactured it, and 21 companies retailed directly to consumers. Results showed that the sampled SMEs have a keen interest in developing sustainable products, albeit at surface level, with most choosing to reduce impact through their material and fibre choices, with less importance placed on manufacturing processes. Other revelations included the low uptake of 3D garment simulation software, designed to reduce the need for multiple prototypes and the reliance on cut and sew processes. This study revealed several areas where environmental impact can be reduced and aims to inform future studies within the knitwear industry focused on material use, product life-cycle analysis, waste reduction and digital technology adoption.

1. Introduction

There is little known research into the knitwear design and manufacture process, despite the rising interest in the wider fashion supply chain due to Corporate Social Responsibility (CSR) goals and environmental impact concerns. Recently, several large global reports have been undertaken by Non-Governmental Organisations (NGOs), private firms, and research conglomerates to further understand the fashion industry and its impact on the environment, garment workers, consumers, and the economy (Quantis, 2018; House of Commons and Environmental A, 2019; Fashion Revolution, 2022; McKinsey & Company, 2022). While these reports are far reaching, issues arise within those which holistically address the apparel product development cycle. For instance, in one such report, where environmental impact at each phase of the supply chain was measured, the knitwear product development system is assumed to follow the same linear system as woven garments, where the knitting of fabric is placed before garment assembly (Quantis, 2018). Whilst this may be the case for cut and sew knitwear processes, it is inaccurate for fully fashioned and seamless knitted garments. Nevertheless, the quantities produced using these methods are unknown.

Knitwear product development is fundamentally different to woven product development. The knitwear designer must understand the characteristics of fibres, yarns, and the performance of stitch structures alongside consideration of the usual aesthetic appeal of trends and the expectations of the intended wearer and the branded identity (Cassidy, 2018). Critically, decision making during the design and production of garments can profoundly influence a garment's overall environmental impact (Earley, 2017), yet few studies have attempted to dissect aspects

Abbreviations: CSR, Corporate Social Responsibility; GOTS, The Global Organic Textile Standard; LCA, Lifecycle Assessment; NGO, Non-Governmental Organization; PSS, Product Specific Service; RMG, Ready Made Garment; SME, Small and Medium Enterprises; SAC, Sustainable Apparel Coalition.

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of knitwear product development, aside from Eckert's investigations of personal relationships between knit technicians and designers, and the lack of innovation in commercial knitwear design (Eckert and Stacey, 1994, 2003; Eckert, 1998, 2006). However, beyond a rudimentary understanding that design decisions are important for the development of sustainable (even circular) products, current research does not attempt to understand the present-day design or product development process at play for knitwear companies.

There are key issues the knitwear industry faces throughout the product development system, including:

- The environmental and ethical impact of fibres
- The volume of material wasted during knitwear garment production
- The inefficiency of prototyping and garment fit
- The slow adoption of digital technologies within design
- A lack of understanding of the use phase of knitwear garments

There are many issues surrounding the environmental credibility of material choice within apparel design. Easily understood amongst consumers is the detrimental impact of synthetic fibres due to high rates of carbon emissions and resource depletion from their production, and the deposition of microplastics into the ecosystem (Salvador Cesa, Turra and Baruque-Ramos, 2017). However, natural fibres and the use of chemicals such as pesticides and nitrates which damage the environment and those who work within it are also of great concern (Bevilacqua et al., 2014). Other issues include the difficulties in recycling both natural and synthetic fibres, particularly once blended. Other, less common but still fractious issues, include the ethical concerns of animal fibre production (Sneddon et al., 2014) and the performance and durability of biodegradable fibres (Jose, Salim and Ammayappan, 2016). It is unclear how these issues impact design decision making within the knitwear industry where wool products are presumed to dominate. Material choice becomes of further concern during manufacturing, where common methods frequently allow yarn to be discarded having never been used.

Within knitwear design there are three main manufacturing processes; fully fashioned, cut and sew, and seamless knitwear. Fully fashioned knitwear involves knitting garment panels to the exact shape required for construction ahead of attachment (Ma and Lamar, 2013). The garment pieces retain all the wales through relocation (Power and Almond, 2019). This production technique is time intensive, as shaping must be done on individual pieces and requires laborious post sewing or linking processes (Choi, Kim and Powell, 2015). Cut and sew manufacturing techniques can be used in a variety of ways, each resulting in different amounts of wasted material. Often, full garment pieces are cut from a knitted length of fabric, alternatively a garment may be fully fashioned, and only the neckline shape is cut out of the garment panel. It is widely understood within the knitwear industry that seamless knitwear is relatively waste free and efficient to produce, yet its uptake within the industry is sparse for commercial knitwear garments. One feasible reason for its modest uptake is believed to be the complexity of design software related to digital seamless knitwear machinery. This digital skills gap has caused various issues, such as infrequent teaching of 3D seamless knitwear in higher education settings (Sayer, Wilson and Challis, 2006), a reliance on the reuse of stock designs resulting in a lack of innovation within the industry (Taylor and Townsend, 2014) and a lack of consumer readiness due to seamless garments mimicking the look of their fully fashioned counterparts (Evans-Mikellis, 2011).

Prototyping has long been a resource depleting stage for knitwear product development, yet it is seen as an essential part of the system for distinct reasons, including the possibility for buyers to see designs before production, as well as evaluating product size and quality. 3D Garment Simulation software has been introduced to the knitwear industry via Shima Seiki's APEX™ program, with the aim of reducing prototyping outputs alongside fashion software such as Clo-3d© and Browzwear®, yet it is unclear whether these advancements have reduced prototyping output. Virtual prototyping workflows have been examined, both for seamless garments (Dong et al., 2018) and for gathered and draped knitted fabrics (Kilinc and Bor Kocoaman, 2019), but despite the potential to reduce the waste generated during prototyping, it is understood that accuracy of colour representation and fit are below standard. It has been theorised that to accurately use such software rigorous and repeatable mechanical and tensile testing of knitted samples must inform and guide the Computer Aided Design (CAD) input (Kilinc and Bor Kocoaman, 2019). Accurate digital prototypes would not only reduce sampling production in the manufacturing stages but change retail experiences, where consumers could personalise, virtually alter fit, and order made-to-measure knitwear, however simulation of realistic material properties and texture requires improvement for consumer satisfaction (Zhou, 2019).

Both online and in-store retailers are customer facing, and have opportunities to use fashion for change, through collaboration with NGOs and charitable organisations, and engagement with the community in which they reside, or often rely on for labour, inspiration, and financial gain. This can often include the safe management of retail waste to avoid localised environmental damage and may entail take back initiatives and Product Specific Services (PSS) such as mending schemes. There is little insight to how successful these schemes are within the fashion industry, let alone the knitwear sector but it has been suggested they are less utilised than expected by consumers (Kant Hvass and Pedersen, 2019). Return rates, dead stock, use, and disposal of garments are matters which brands are under pressure to acknowledge and intervene, as consumers become more aware of the ever-present impact of their shopping habits. However, once again it is unclear how the knitwear industry assesses its impact on consumers, the environment, and the community.

From a supply chain perspective, SMEs (both suppliers and retailers) were found to be the ideal partners for developing innovative products and processes (Battaglia et al., 2014). At the start of 2021 SMEs accounted for 99.9% of the UK business population. For the EU fashion sector, there are approximately 178,000 fashion businesses, with 59,000 fashion SMEs in the UK alone (Centre for Sustainable Fashion and British Fashion Council, 2019). SMEs play a key role as agents of change to the fashion sector. Due to their size, business models can be niche and adaptive to nuance and change, despite being open to risk from a lack of capital. Due to the transformative role SMEs play within the fashion sector and the knowledge gap of knitwear SMEs, they have been the focus of this study. This paper results in a better understanding of knitwear SMEs, from the decisions in the product development process, to the machineries tools and processes in use, and their position for change in the fashion supply chain.

2. Methods

A questionnaire was designed, targeting SMEs involved with the design and manufacture of knitwear. An introductory section characterises the companies into micro/small/medium sizes in relation to the European Union SME definitions, which outline:

- A micro business as a company with fewer than ten employees and an annual turnover of less than £2,000,000.
- A small-sized business as a company with fewer than 50 employees and an annual turnover of less than £10,000,000.
- A medium-sized business as a company with fewer than 250 employees and an annual turnover of less than £50,000,000.

Within the knitwear design and manufacturing ecosystem, four company types were identified:

- Design agencies (also known as swatch agencies) who sell design ideas
- Manufacturers who produce a brand's design ideas
- Brands who design knitwear and consult with manufacturers to produce their designs
- Designer makers who design and manufacture in-house

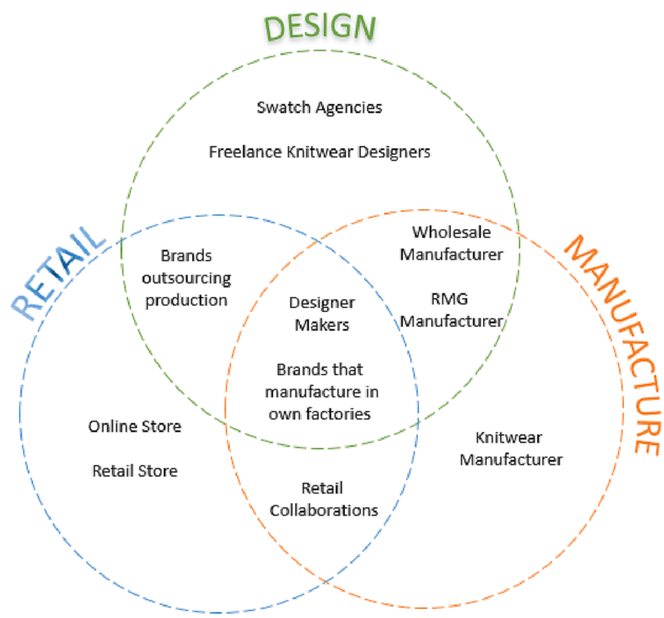

Fig. 1. Company Types and Knitwear Phases.

The knitwear product development cycle was evaluated and clustered across three key phases: design, manufacture and retail. Fig. 1 shows the range of company types active within the knitwear industry and their dynamic nature. To ensure knitwear companies from all phases could interact with the study, the questionnaire was split into these three phases with eligibility for the forthcoming section, as shown in the questionnaire map (Fig. 2) along with themes of questions for each section.

Participant SMEs were recruited via advertisements in the 'Knitting Industry' journal as part of the World Textiles Information Network (WTIN) publication. The Knitting Industry journal was identified as a preferable place to market the questionnaire due to its importance and popularity amongst companies common amongst the three phases identified within the knitwear product development system.

3. Calculation

The online questionnaire consisted of a range of multiple-choice questions, selection list questions and free text questions. Multiple-choice questions were chosen for subject areas such as material use, software availability, design ideation, machinery availability and other limitless datasets. Selection list questions were designed for datasets which were continuous, for instance for investigating lead times and for other factual areas. Often after a quantitative question, participants were able to elaborate further and offer comment, which allowed for driving forces behind decision-making within the knitwear product supply chain to be further understood. Data was analysed through indexing of company behaviours and themes, then patterns and connections identified using content analysis.

4. Results

In total, 31 companies from around the world and of varying sizes responded to the questionnaire. A breakdown of the origins of these companies follows is shown in Table 1. Subsequent results are separated into the three phases identified, with the gathered data displayed in tables and reported on.

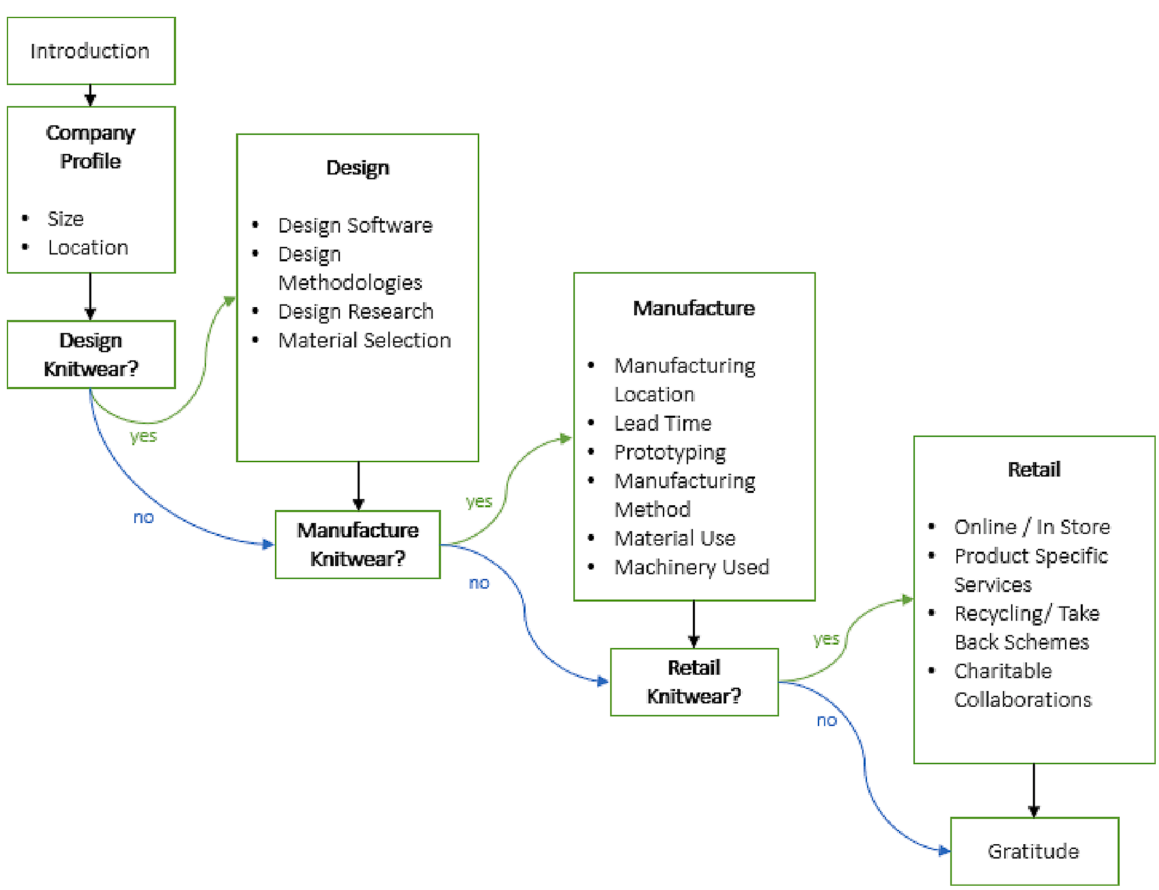

Fig. 2. Questionnaire Map.

Table 1
Company Profile.

Company Profile	Quantity	%		Quantity	%
Q1. Company Origin			**Q2. Company Size**		
Europe	**20**	64.5%	Micro	**18**	58.1%
Asia	**4**	12.9%	Small	**8**	25.8%
North America	**4**	12.9%	Medium	**5**	16.1%
Australia	**2**	6.5%			
Africa	**1**	3.2%			
Total	31				
Q3. Company Roles:					
Design	**26**	83.8%			
Manufacture	**25**	80.6%			
Retail	**21**	67.7%			

4.1. Design

As illustrated in Table 2, 26 respondents designed knitwear, six were design agencies, six manufacturers, five designer makers, five designer makers (with some outsourced manufacturing) and four brands, who subcontract the manufacturing of all products. The responses to the design phase of the questionnaire are presented.

Companies selected multiple design research opportunities and *new conceptual research* was the most selected mode of inspiration, closely followed by *market research*. Respondents were asked which singular design method they primarily used. Nine respondents relied on knit design software to generate design ideas, with five of those using Stoll M1® Plus software, and three using Shima APEX™ software. Unsurprisingly, the reported reason for using knit design software was its compatibility with the corresponding own brand of knitwear machinery but two respondents who relied mostly on knit design software considered accuracy as a reason for its use.

Illustration by hand was almost as prevalent an ideation technique as using knit design software, despite the advances in CAD illustration and garment simulation software. Of those respondents using illustration processes by hand, seven were categorised as micro-entities and one a small enterprise. Further investigation showed three respondents who relied on illustration by hand, were design agencies who do not manufacture or subcontract production and three subcontracted productions, suggesting that designers are using analogue processes for creativity, as CAD tools are little required when no production is undertaken. Wools were the most utilised amongst all design businesses. Other natural fibres such as cottons and animal fibres were also ever present within

Table 2
Design Questionnaire Results.

Design Respondents					
Q1. Select the company type:			**Q2. Select the products in the designed ranges:**		
Design Agency	**6**	23.1%	Women's Knitwear	**24**	92.3%
Manufacturer	**6**	23.1%	Men's Knitwear	**16**	61.5%
Designer Maker	**5**	19.2%	Knitted Accessories	**14**	53.8%
Designer Maker (with some outsourced manufacturing)	**5**	19.2%	Childrenswear	**9**	34.6%
Brand (who subcontracts manufacturing of all products)	**4**	15.4%	Footwear	**4**	15.4%
			Functional Sportswear	**4**	15.4%
			Hosiery	**1**	3.8%
Q3. Select the design research method:			**Q3a.** ***(If selected 'Re-Design of Stock Garments' in Q3)*** **Select the Re-Design Processes in use:**		
New Conceptual Research	**22**	84.6%	Knitwear Design Software	**7**	77.8%
Market Research	**20**	76.9%	Fashion Illustration by Hand	**4**	44.4%
Trade Shows	**12**	46.2%	General CAD Illustration Software	**3**	33.3%
Trend Magazines and Journals	**11**	42.3%	Traditional Pattern Cutting Techniques	**3**	33.3%
Catwalk Shows	**10**	38.5%	3D Garment Simulation Software	**1**	11.1%
Re-Design of Stock Garments	**9**	34.6%	Fashion Design Software	**1**	11.1%
Trend Consultation	**8**	30.8%			
Q3b. ***(If selected 'Knitwear Design Software' in Q3a)*** **State the Knitwear Design Software in use:**			**Q4. Select the primarily utilised design method:**		
Shima APEX™	**5**	71.4%	Knit Design Software	**9**	34.6%
Stoll M1 Plus®	**1**	14.3%	Illustration By Hand	**8**	30.8%
Designa-Knit	**1**	14.3%	General CAD Illustration Software	**3**	11.5%
Browzwear®	**1**	14.3%	Sampling on Machinery	**3**	11.5%
Unsure	**1**	14.3%	Garment Simulation Software	**1**	3.8%
			Traditional Pattern Cutting	**1**	3.8%
			Draping On the Stand	**1**	3.8%
Q5. Do designers have knowledge of manufacturing processes?			**Q6. Do designers select the manufacturing processes?**		
Yes	**21**	80.8%	Yes	**18**	69.2%
No	**1**	3.8%	Mostly	**3**	11.5%
Unsure	**4**	15.4%	Rarely	**2**	7.7%
			No	**2**	7.7%
			Unsure	**1**	3.8%
Q7. Select the materials in your product ranges:			**Q8. Materials with environmental attributes are used in…**		
Wool	**23**	88.5%	All Products	**11**	42.3%
Cotton	**20**	76.9%	Some Products	**11**	42.3%
Cashmere	**15**	57.7%	No Products	**1**	3.8%
Silk	**13**	50.0%	Unknown	**3**	11.5%
Viscose	**12**	46.2%			
Alpaca	**11**	42.3%			
Nylon	**11**	42.3%			
Elastane	**8**	30.8%			
Acrylic	**8**	30.8%			
Polyester	**7**	26.9%			
Lyocell	**6**	23.1%			
Modal	**5**	19.2%			
Aramid	**1**	3.8%			
Acetate	**1**	3.8%			

(*continued on next page*)

Table 2 (*continued*)

Design Respondents					
Polylactic Acid	**1**	3.8%			
Mohair	**1**	3.8%			
Linen	**1**	3.8%			
Pineapple	**1**	3.8%			
Q8a. *(If selected 'All Products' or 'Some Products' in Q8)* Select the materials with environmental attributes in use:			**Q8b. *(If selected 'Animal Fibre' in Q8)* Select the Animal Fibres in use: Select the Animal Fibres in use:**		
Animal Fibre	**9**	40.9%	Organic Wool	**7**	77.8%
Plant Fibre	**6**	27.3%	Responsible Wool Standard (RWS)	**7**	77.8%
Regenerated Fibre	**4**	18.2%	Recycled Wool	**3**	33.3%
Synthetic Fibre	**1**	4.5%	Recycled Cashmere	**3**	33.3%
Unknown	**2**	9.1%	Organic Mohair	**1**	11.1%
			Traceable Down Standard (TDS)	**1**	11.1%
Q8c. *(if selected 'Plant Fibre' in Q8)* Select the Plant Fibres in use: Select the Plant Fibres in use:			**Q8d. *(if selected 'Regenerated Fibres' in Q8)* Select the Regenerated Fibres in use:**		
Organic Cotton	**5**	83.3%	Lyocell (FSC, PEFC)	**4**	100.0%
GOTS Certified Organic Cotton	**5**	83.3%	Viscose (FSC, PEFC)	**1**	25.0%
Fair Trade Cotton	**4**	66.7%	Recycled Cellulose	**1**	25.0%
Better Cotton Initiative	**2**	33.3%			
BioRE	**1**	16.7%			
Regenerated Organic Certified (ROC) Cotton	**1**	16.7%			
Pineapple Fibre	**1**	16.7%			
Recycled Cotton	**1**	16.7%			
Q8e. *(if selected 'Synthetic Fibre' in Q8)* Select the Synthetic Fibres in use:			**Q9. Is the environmental and social impact of the materials used assessed?**		
Bio Based Polyester	**1**	100.0%	Yes	**9**	34.6%
Recycled Polyester	**1**	100.0%	No	**17**	65.4%
Q9a. *(If selected 'Yes' in Q9)* Select the Assessment Method:					
Environmental Life Cycle Impact Assessment	**4**	44.4%			
The Higg Index	**2**	22.2%			
Social Life Cycle Impact Assessment	**2**	22.2%			
Closed Loop Life Cycle Impact Assessment	**2**	22.2%			
Environmental Impact Assessment (unregulated)	**1**	11.1%			
Environmental Risk Assessment (European Commission)	**1**	11.1%			
Strategic Environmental Assessment (European Commission)	**1**	11.1%			
Unregulated Risk Assessment	**1**	11.1%			

knitwear product ranges. Synthetic fibres were also present, with many using acrylic, polyester and elastane within their ranges. The proportion of micro-businesses using synthetic materials within their ranges was significantly lower than natural fibres and marginally lower for small businesses, with some reliant on acrylic fibres, as shown in Fig. 3.

Material choice was the most crucial factor in terms of sustainability for designers. 11 respondents used environmentally preferred materials, or materials with environmental attributes in all their products, 11 did this with only some of their product range. New material innovations such as pineapple fibre were also present within the responses. Synthetic

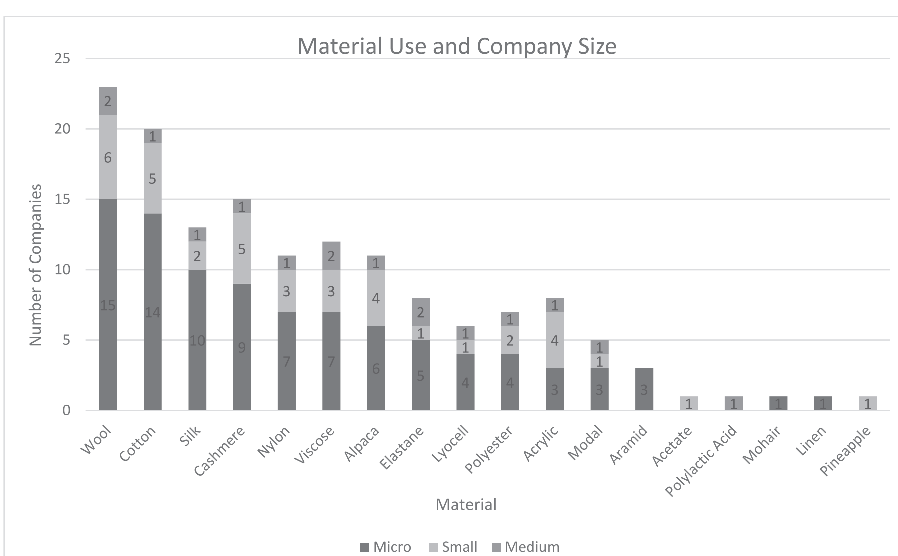

Fig. 3. Overall Material Use and Company Size.

fibres were the least utilised in relation to sustainable materials, with only one respondent using bio-based recycled polyesters. Assessment of the environmental and social impact of materials was seldom done, however rarely the Environmental Life Cycle Impact Assessment (Cradle to Grave) was used.

4.2. Manufacturing

25 of the 31 respondents reported as manufacturers of knitwear, either through subcontractors, in-house manufacturing, or a combination of both. The six respondents who did not manufacture knitwear, were design agencies who sell design ideas to brands and take no part in the upscaling of products. Of those who outsourced manufacturing partially or fully, the maximum manufacturing locations used were three facilities. Most manufacturers stated that products were completed in under 12 weeks, but answers ranged from two weeks to 26 weeks. Companies recording the shortest lead times such as one to two weeks were micro entities, whilst one micro entity stated six months.

Table 3
Manufacturing Questionnaire Results.

Manufacturing Respondents	**Quantity**	**%**		**Quantity**	**%**
Q1. Select your Manufacturing Role:			**Q1a.** ***(If selected that outsourcing occurs in Q1)*** **Select the quantity manufacturing facilities outsourcing too:**		
Manufacturer of other company's products	**9**	29.0%	1 facility	**2**	18.1%
Manufacture some products in house and subcontract others	**7**	22.5%	2 facilities	**3**	27.3%
Design Agency (Not involved in any manufacturing)	**6**	19.5%	3 facilities	**3**	27.3%
Manufacture own products in house	**5**	16.1%	4 facilities	**2**	18.1%
Subcontract the manufacturing of all products	**4**	12.9%	Unknown	**1**	9.2%
Q2. Select the manufacturing regions:			**Q2a.** ***(If stated "Multiple Regions" in Q2)*** **Specify the Locations (comments)**		
United Kingdom	**10**	40.0	Australia, China, India Peru		
European Union	**4**	16.0%	North America / Asia		
Multiple Regions	**2**	8.0%			
Southeast Asia	**2**	8.0%	**Q2b. Which term best describes the manufacturing location?**		
Middle East	**2**	8.0%	In House	**15**	60%
Eastern Europe	**1**	4.0%	Onshore	**3**	12%
Central Asia	**1**	4.0%	Offshore	**3**	12%
Africa	**1**	4.0%	Mixed	**3**	12%
North America	**1**	4.0%	Unknown	**1**	4%
Oceania	**1**	4.0%	Nearshore	**0**	0%
Q3. Select the maximum lead times of a product:			**Q4. Select the usual quantity of prototypes made:**		
2 Weeks	**2**	8%	1	**1**	4%
4 Weeks	**1**	0%	2	**15**	60%
6 Weeks	**3**	16%	3	**4**	16%
8 Weeks	**4**	16%	4	**3**	12%
10 Weeks	**2**	8%	5+	**2**	8%
12 Weeks	**4**	12%			
14 Weeks	**1**	4%			
16 Weeks	**1**	4%			
18 Weeks	**1**	4%			
20 Weeks	**0**	0%			
22 Weeks	**1**	4%			
24 Weeks	**0**	0%			
26 Weeks	**2**	4%			
Unknown	**3**	20%			
Q5. Multiple Prototype Rationale			**Q6. Knit Machinery**		
Fit Issues	**9**	36%	Shima Computerised Flat Machine	**14**	60.9%
Design Flaws	**6**	24%	Domestic Knitting Machine	**5**	21.7%
Programming Requirement	**4**	16%	Industrial Overlocker	**5**	21.7%
Grading Issue	**2**	8%	Shima Wholegarment Machine	**5**	21.7%
Customer Changing Mind	**2**	8%	Shima Glove / Sock Knitting Machine	**4**	17.4%
Manufacturing Fault	**1**	4%	Stoll CMS 520	**4**	17.4%
All the above	**1**	4%	Shima Yarn Unwinding Option	**3**	13%
			Stoll CMS 530 KI	**3**	13%
			Stoll ADF 530	**2**	8.7%
			Complett Linking Machines	**2**	8.7%
			Dubied	**2**	8.7%
			Hague Industrial Linker	**2**	8.7%
			Shima Tension measuring Machine	**1**	4.3%
			Seamless Santoni SM8	**1**	4.3%
			Domestic Overlocker	**1**	4.3%
			Cixing GE252C	**1**	4.3%
			Bentley Cotton Frames	**1**	4.3%
			Older Stoll Models	**1**	4.3%
			Rimoldi Industrial Linking Machines	**1**	4.3%
Q7. Do you use the Cut and Sew Manufacturing Processes?			**Q7a.** ***(if selected any Cut and Sew process in Q7)*** **Select the material in Cut and Sew knitwear:**		
Complete	**4**	16%	Wool	**9**	75%
Partial	**4**	16%	Cotton	**7**	58.3%
Complete and Partial	**4**	16%	Acrylic	**4**	33.3%

(*continued on next page*)

Table 3 (*continued*)

Manufacturing Respondents	**Quantity**	**%**		**Quantity**	**%**
Unsure	**3**	12%	Viscose/Rayon	**4**	33.3%
No	**10**	40%	Nylon	**3**	25%
			Cashmere	**2**	16.7%
			Acetate	**1**	8.3%
			Alpaca	**1**	8.3%
			Aramid	**1**	8.3%
			Carbon Fibre	**1**	8.3%
			Elastane	**1**	8.3%
			Modal	**1**	8.3%
			Polyester	**1**	8.3%
			Silk	**1**	8.3%
			Polyurethane	**1**	8.3%
Q7b. ***(if selected any Cut and Sew process in Q7)*** **Select the waste management route used:**			**Q7c.** ***(if selected any Cut and Sew process in Q7)*** **Select the reason for using Cut and Sew processes:**		
Recyclers	**4**	16%	Design Specified	**7**	58.3%
Unknown	**3**	12%	Machinery Availability	**7**	58.3%
Landfill	**2**	8%	Pattern unachievable otherwise	**5**	41.7%
Waste Disposal	**2**	8%	Manufacturing Speed	**3**	25%
Reused in house	**1**	4%	Cost	**2**	16.7%
			Material Consumption	**2**	16.7%
			Aesthetics	**1**	8.3%
			Energy Use	**1**	8.3%
			Performance Enhancement for wearer	**1**	8.3%
			Unknown	**1**	8.3%
Q7d. ***(if selected any Cut and Sew process in Q7) Select the products using the Cut and Sew processes:***					
Jumpers	**9**	75%			
Cardigan	**5**	41.7%			
T-Shirt	**3**	25%			
Other	**3**	25%			
Trousers	**2**	16.7%			
Skirt	**2**	16.7%			
Dresses	**2**	16.7%			
Shirt	**1**	8.3%			
Leggings	**1**	8.3%			
Underwear	**1**	8.3%			
Swimwear	**1**	8.3%			
Socks	**1**	8.3%			
Accessories	**1**	8.3%			
Footwear	**1**	8.3%			
PPE	**1**	8.3%			
Outerwear	**1**	8.3%			
Q8. Do you use the Fully Fashioned Manufacturing Processes?			**Q8a.** ***(if selected 'Yes' in Q8)*** **Select the material in Cut and Sew knitwear:**		
Yes	**17**	68%	Wool	**12**	80%
No	**4**	16%	Cotton	**8**	53.3%
Unsure	**4**	16%	Cashmere	**7**	46.7%
Q8b. ***(if selected 'Yes' in Q8)*** **Select the waste management route:**			Nylon	**5**	33.3%
Recyclers	**3**	18%	Viscose/Rayon	**4**	26.7%
Unknown	**9**	52%	Alpaca	**2**	13.3%
Landfill	**4**	24%	Polyester	**2**	13.3%
Waste Disposal	**1**	6%	Silk	**3**	20%
			Polyurethane	**1**	6.7%
			Mohair	**1**	6.7%
			Aramid	**1**	6.7%
			Carbon Fibre	**1**	6.7%
			Glass Fibre	**1**	6.7%
			Polypropylene	**1**	6.7%
			Acetate	**1**	6.7%
			Acrylic	**1**	6.7%
Q8c. (***if selected 'Yes' in Q8)*** **Select the reason for using Fully Fashioned Processes:**			**Q8d.** (***if selected 'Yes' in Q8)*** **Select the products using Fully Fashioned processes:**		
Material Consumption	**10**	62.5%	Jumpers	**15**	88.2%
Design Specified	**8**	50%	Cardigan	**14**	82.4%
Aesthetics	**7**	43.8%	Accessories	**8**	47.1%
Quality Assurance	**7**	43.8%	Skirt	**4**	23.5%
Machinery Availability	**5**	31.3%	Trousers	**3**	17.6%
Performance Enhancement for wearer	**4**	25%	Leggings	**3**	17.6%
Comfort	**4**	25%	T-Shirt	**2**	11.8%
Manufacturing Speed	**3**	25%	Outerwear	**2**	11.8%
Cost	**3**	18.8%	Sportswear	**2**	11.8%
Energy Use	**3**	18.8%	Socks	**2**	11.8%
			Shirt	**1**	5.9%
			Underwear	**1**	5.9%
			Dresses	**1**	5.9%
			Hosiery	**1**	5.9%

(*continued on next page*)

Table 3 (*continued*)

Manufacturing Respondents	Quantity	%		Quantity	%
			Shorts	1	5.9%
			Footwear	1	5.9%
Q9. Do you use Seamless Manufacturing Processes?			**Q9a. (*if selected 'Yes' in Q9*) Select the Material in the Seamless Knitwear:**		
Yes	**8**	32%	Wool	**5**	71.4%
No	**15**	60%	Cashmere	**2**	28.6%
Unsure	**2**	8%	Acetate	**1**	14.3%
			Carbon Fibre	**1**	14.3%
Q9b. (*if selected 'Yes' in Q9*) Select the waste management route:			Glass Fibre	**1**	14.3%
Recyclers	**3**	18%	Alpaca	**1**	14.3%
Unknown	**9**	52%	Polyester	**1**	14.3%
Landfill	**4**	24%	Silk	**1**	14.3%
Waste Disposal	**1**	6%	Polylactic Acid	**1**	14.3%
			Cotton	**1**	14.3%
			Nylon	**1**	14.3%
Q9c. (*if selected 'Yes' in Q9*) Select the reason for using Seamless processes:			**Q9d. (*if selected 'Yes' in Q9*) Select the products using Seamless processes:**		
Material Consumption	**4**	57.2%	Jumpers	**6**	85.7%
Manufacturing Speed	**3**	42.9%	Trousers	**4**	57.1%
Design Specified	**2**	28.6%	Cardigan	**2**	28.6%
Aesthetics	**1**	14.3%	Leggings	**2**	28.6%
Quality Assurance	**1**	14.3%	Sportswear	**2**	28.6%
Machinery Availability	**1**	14.3%	Socks	**1**	14.3%
Performance Enhancement for wearer	**1**	14.3%	PPE	**1**	14.3%
Comfort	**1**	14.3%	Accessories	**1**	14.3%
Energy Use	**1**	14.3%	Skirt	**1**	14.3%
			T-Shirt	**1**	14.3%

4.2.1. *Prototyping*

Responses indicate that prototyping still takes up a sizeable proportion of the design and manufacturing lead time, with one respondent explaining that they have had samples require up to six months to be approved ready for production, while other responses stated from two to six weeks. Only small and medium sized businesses stated that they regularly made prototypes over five times, as shown in Fig. 4.

Additional comments from respondents were *"no sample ever comes right the first time around. If someone creates the perfect fit the first time around, I will hire them."* This comment was from a respondent who used

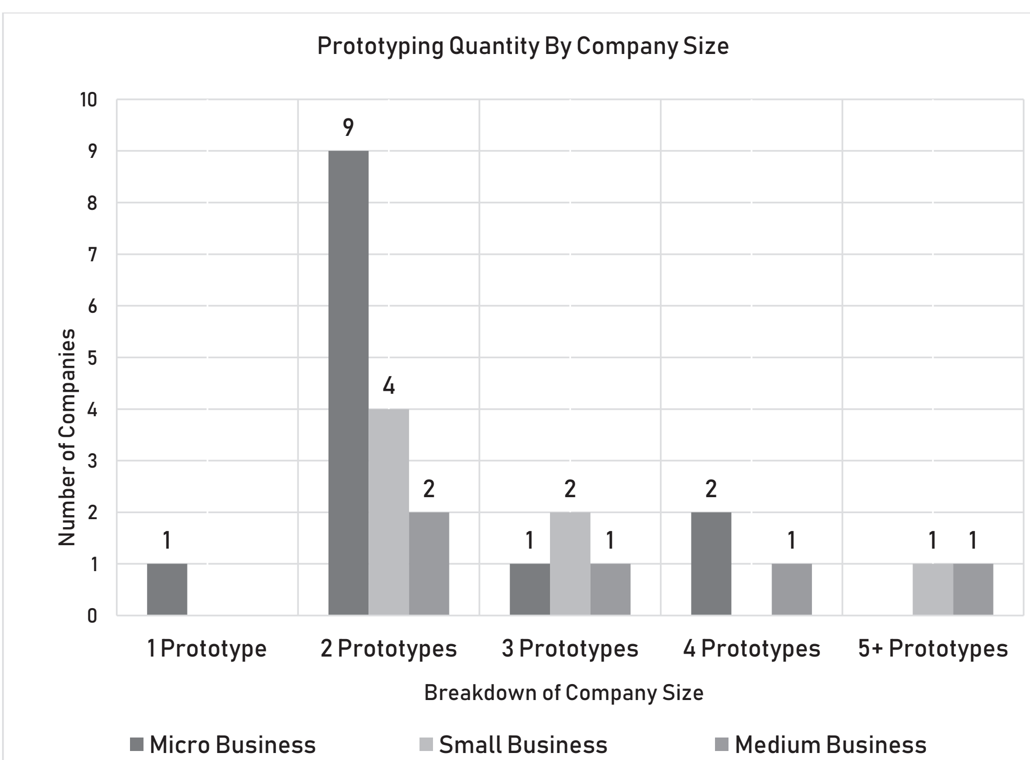

Fig. 4. Prototyping by Company Size.

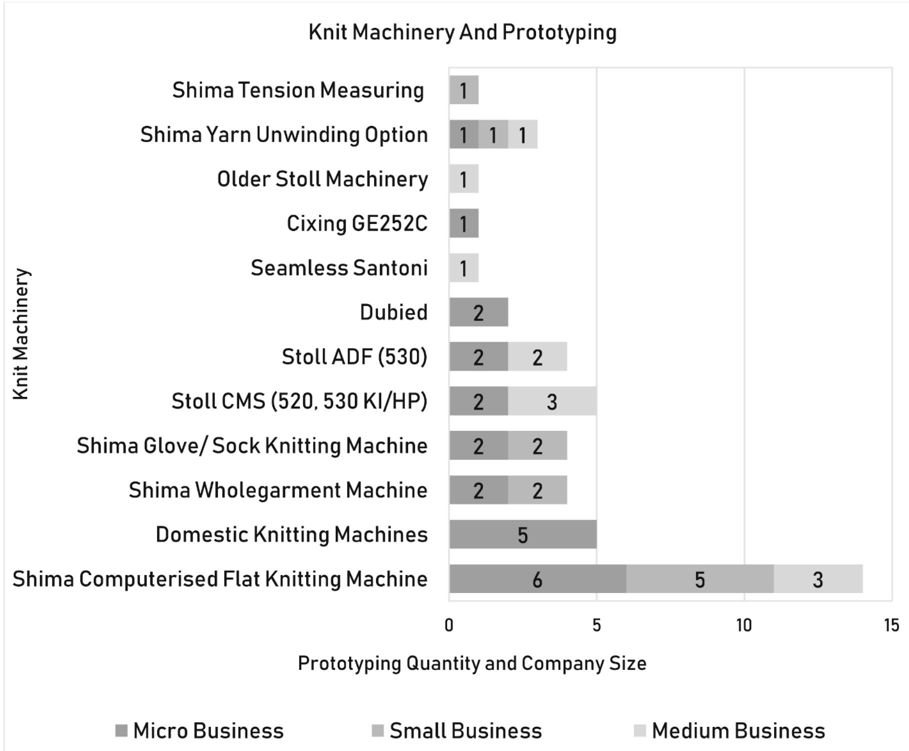

Fig. 5. Knit Machinery and Prototyping.

Shima Seiki machinery, which has inbuilt 3D Garment Simulation software, designed to improve fit, replace physical prototyping, and have increased accuracy. A breakdown of the machinery in use and company size is shown in Fig. 5. Of the 14 respondents who stated they used Shima Seiki machinery to create garments, four stated they mostly remade physical prototypes due to design flaws and three stated it was due to fit issues. Of the six respondents who stated they used Stoll machinery, three said issues with fit resulted in the need to manufacture multiple prototypes.

Small and medium sized businesses had issues with design customers changing their opinion on features they would like within their garments, causing updates and therefore new prototypes (Fig. 6). In general, issues which rely heavily on knit calculation, such as fit issues, grading and design flaws, were the most common causes for needing to generate multiple prototypes. Of those who prototyped more, synthetic fibres were commonly in use alongside animal fibres, and those who completed two or less prototypes relied on plant, animal, or regenerated fibres (Fig. 7).

4.3. *Knit machinery*

The most utilised model of knitwear machinery amongst respondents was Shima Seiki computerised flat knitting machines (both in-house and

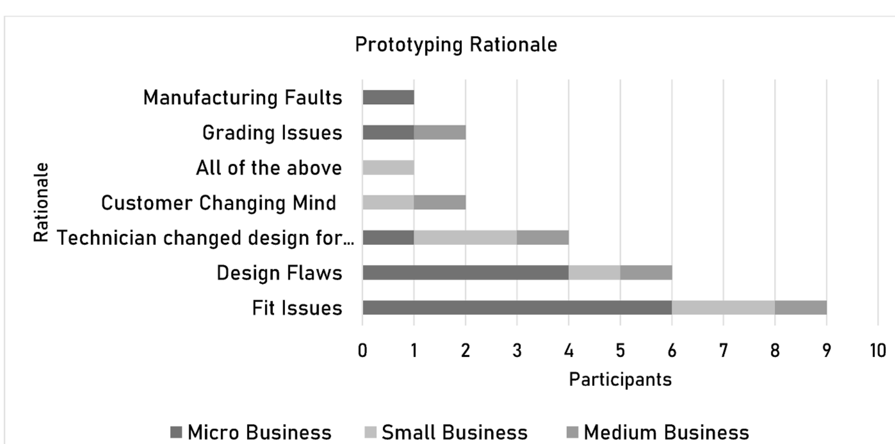

Fig. 6. Prototyping Rationale by Company Size.

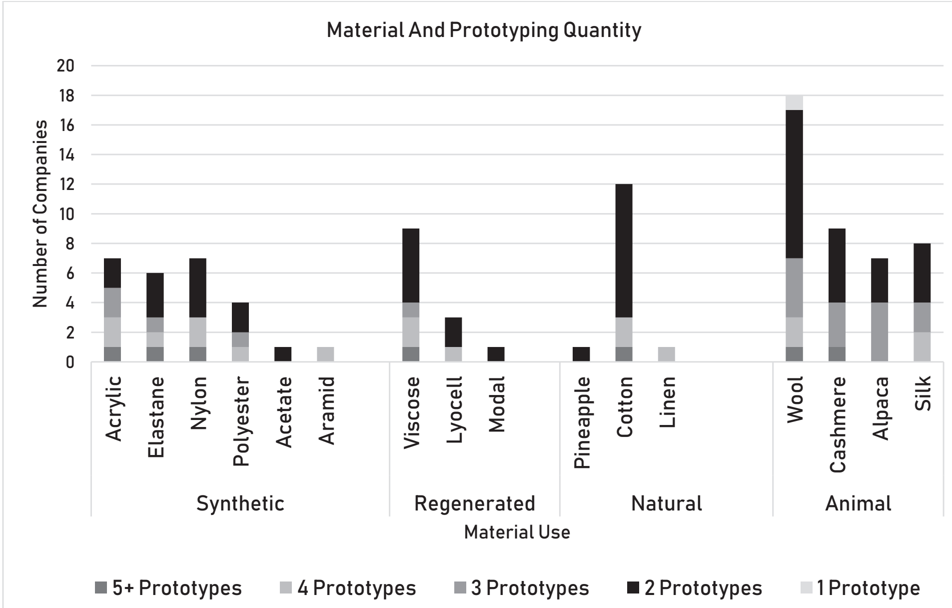

Fig. 7. Material and Prototyping Quantity.

outsourced) followed by Stoll CMS machinery, few stated that Shima Wholegarment® machinery was utilised, despite its capability to reduce waste and postproduction labour. A complete overview of responses by knitting machinery is shown in Table 3. Medium sized companies with products made on Shima Seiki machinery made much larger units, with annual unit sales of up to 1 million and 2.5 million units.

4.4. *Manufacturing process*

Of the 25 respondents who manufacture knitwear in house or outsourced:

- 17 used fully fashioned manufacturing methods
- 12 used cut and sew methods
- 8 used Seamless knitwear methods

4.4.1. *Cut and sew knitwear*

Questions relating to the cut and sew manufacturing processes utilized were split into three sections:

- Complete cut and sew: where full garment pieces are cut
- Partial cut and sew; where other techniques such as fully fashioning are used, but cut and sew trims/necklines are added
- Complete and partial cut and sew; where some products are made using complete cut and sew, and others using partial methods

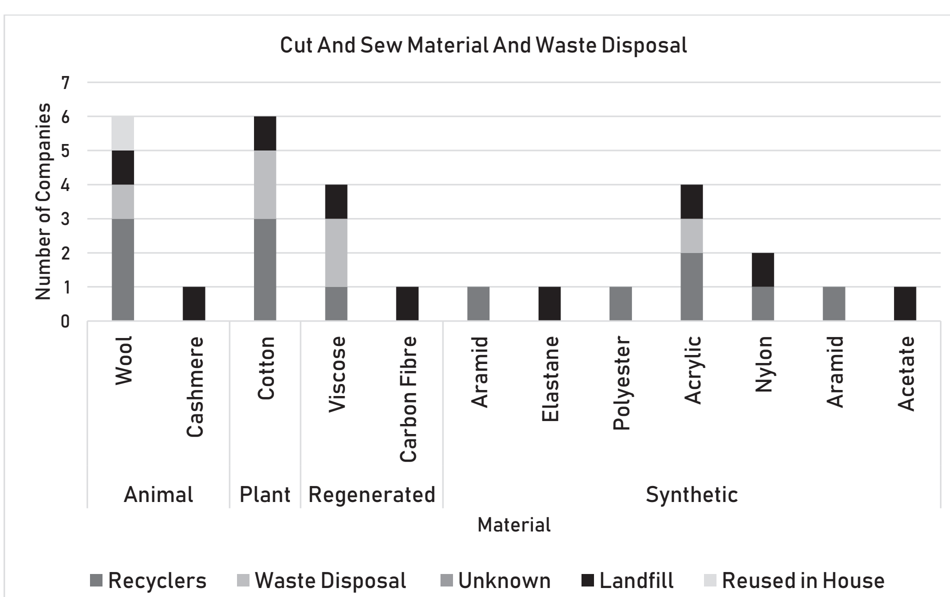

Fig. 8. Cut and Sew Material and Waste Disposal.

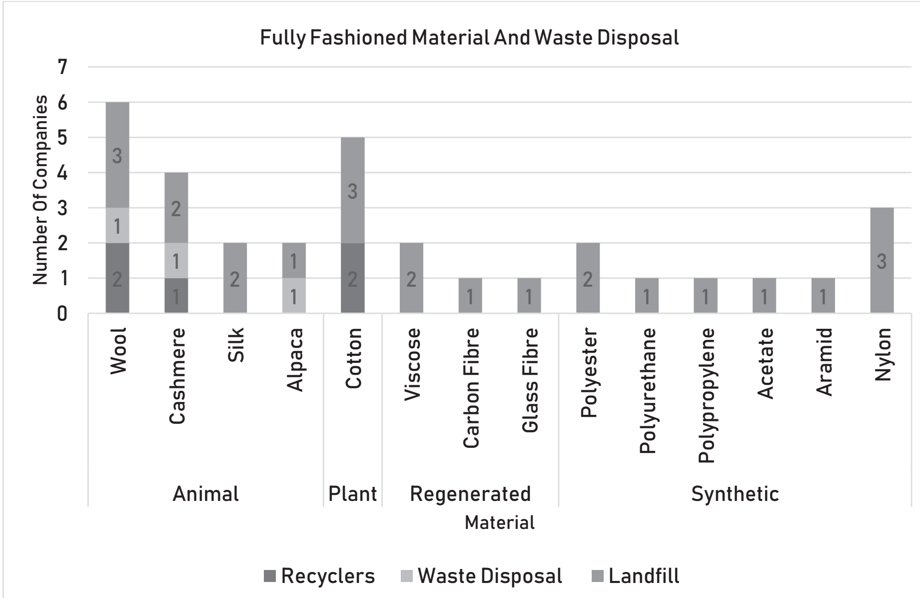

Fig. 9. Fully Fashioned Material and Waste Disposal.

Results indicate that 12 of respondents used the cut and sew manufacturing process and ten chose not to use cut and sew techniques at all. The amounts of knitwear produced by companies using cut and sew process varied, with some respondents reporting lesser amounts such as 50 units, while others reported manufacturing 2.5 million units of cut and sew knitwear within the last year. Wool was the most selected choice for those who manufactured cut and sew knitwear. The material choice was compared with the disposal route as shown in Fig. 8, and natural (animal or plant) fibres were more likely to be recycled, alongside regenerated fibres.

Respondents were asked to select why cut and sew knitwear remained in use within their product development process. It was claimed that the design specified to use this process, which supports the previous findings where designers needed to consider waste within the initial product development stages. Of those who stated that the pattern of the knit fabric would be unachievable otherwise the majority used partial cut and sew garments, where necklines were cut from patterned fabric and the complexity of managing to quality control the pattern repeat over both sides of the neckline. This may explain why 75% of respondents created jumpers using cut and sew methods.

4.4.2. Fully fashioned

Fully fashioned knitwear was the most used manufacturing technique, with 17 (68%) stating they used it within their product range. Unit quantities ranged from small amounts such as 65 units, up to 17,000 units. Ten respondents (59%) stated over 90% of their product ranges were fully fashioned. Those who manufactured using fully fashioned techniques mostly made jumpers and cardigans. Nine (52%) companies did not know how material waste was disposed of and four (24%) sent waste to landfill. Interestingly, only natural fibres were recycled or managed by waste management companies and synthetic or composite fibres were commonly sent to landfill, shown in Fig. 9. Fully Fashioning processes were popular due to the lesser amounts of material used and the aesthetic of the resultant knit.

4.4.3. Seamless

Seamless knitwear was the least prevalent manufacturing process with only eight (32%) reporting to currently manufacture garments using this method. Quantities of seamless knitwear were smaller, with 10,000 units being the largest reported. Companies who created seamless knitwear only had a small proportion of their product ranges manufactured seamlessly, with only one respondent using seamless knitwear for 100% of their product range, all other respondents used seamless knitwear in less than 20% of their overall product range. Again, wool was the most selected fibre used within seamless knitwear, while cottons, which were popular choices in the previous manufacturing methods, were only selected by 14% of seamless manufacturing respondents. Those who manufactured seamless garments created less accessories, cardigans and outerwear items compared to the previous reviewed techniques. It is unsurprising that material consumption was found to be the most prevalent reason behind using this production method.

4.5. Retail

21 (68%) respondents sold directly to customers through online or retail stores. Of those that sold directly to customers only six (29%) assessed the customer use of retail products in terms of environmental sustainability. 15 (71%) companies did not choose to actively engage and collaborate with their local community, non-governmental organisations and/or governments to facilitate sustainable change. 11 (53%) respondents did not collaborate with charitable organisations in anyway. The means which remaining respondents collaborated with charitable organisations is shown in Table 4.

17 (81%) retail respondents did not offer customers a company take back initiative scheme. An area which positioned knitwear retailers to have a positive consideration of the use phase of a product was through Product Specific Services (PSS), where brands may offer the upkeep (fixing, replacing of parts, mending) of a product. Results implied that knitwear brands are streamlining operations into an on-demand production model which may result in less surplus stock and therefore waste. Of those who reported products that were ready-made, surplus stock was managed in numerous ways shown in Table 4.

Table 4
Retail Questionnaire Results.

Retail Respondents	Quantity	%		Quantity	%
Q1. Do you sell directly to customers online or in retail stores?			**Q2. Do you assess the environmental impacts of the use of its products?**		
Yes	**21**	67.7%	Yes	**6**	28.6%
No	**10**	32.3%	No	**15**	71.4%
Q2a. (*if selected 'Yes' in Q2)* Select the assessment method used:			**Q3. Do you engage with community groups, NGOs, and/or governmental departments to facilitate sustainable change?**		
Secondary Assessment (from a manufacturer)	**3**	50%	No	**15**	71.4%
Informal / Internal assessment	**2**	33.3%	Yes	**6**	28.6%
The Higg Index	**1**	16.6%			
Q4. Do you collaborate with charitable organisations?			**Q5. Select which products have a Take Back Initiative (where clothes can be returned for reuse/recycling):**		
No	**11**	52.4%	No products	**17**	81%
Yes- Local Community Charities	**3**	14.3%	Own Brand Clothing	**3**	14.3%
Yes- A donation from each sale	**2**	9.5%	Specific products	**1**	4.8%
Yes- We donate Sellable Stock	**2**	9.5%			
Yes- A Donation of our overall profit	**1**	4.8%			
Yes- Through Promoting Causes	**1**	4.8%			
Q6. Does your company maintain a Product Specific Service where garments can be sent back for repair and maintenance?			**Q7. Select which products are made to order:**		
No	**14**	66.7%	Some Products	**12**	57.1%
Yes	**7**	33.3%	All Products	**6**	28.6%
			No Products	**3**	14.3%
Q8. Select how surplus stock is managed:					
Donated to Charitable Organisations	**6**	40%			
Discounted for easier sale	**6**	40%			
Sold as wholesale to other organisations	**4**	26.7%			
Donated to organisations	**3**	20%			
Recycled	**3**	20%			
Upcycled	**3**	20%			

5. Discussion

Overall, the results showed that SMEs throughout the knitwear industry have a keen interest in developing sustainable products, with most companies choosing to reduce impact through their material and fibre choices. The knitwear industry was less reliant on synthetic fibres than natural fibres such as animal or plant derived yarns. 17 companies in total used some type of synthetic material within their product ranges. Of these companies 16 (94%) also used cotton and wool which could imply that blended fabrics are still widely at use within the knitwear industry despite the difficulty in recycling composite yarns. The proportion of micro entities using synthetic materials within their ranges was significantly lower than the proportion using natural fibres, and marginally lower for small businesses, with few reliant on acrylic fibres. Medium sized enterprises who reported use of synthetic fibres had unit sales of up to one million units, identifying them as a larger brand/ supplier.

An interesting outcome of the questionnaire was that knitwear brands and manufacturers considered alternative materials to be the most sustainable. The most common environmentally preferred materials were environmentally attributed wools and cottons such as Responsible Wool Standard (RWS) and Global Organic Textiles Standard (GOTS) certified cotton, yet various other materials such as synthetics were chosen. Some knitwear design and manufacture SMEs also consider material usage a crucial factor when manufacturing knitwear products, as reflected through uptake of fully fashioned knitwear, which 68% of manufacturing respondents relied on. Despite this, those who used fully fashioned processes did not manage waste thoroughly, with 52% of companies unaware of how waste was processed possibly due the perceived low material consumption. Some companies who responded added comments stating only the yarn ends and waste yarn is disposed of, but also reported unit sales of 17,000. Despite the high uptake of fully fashioning methods, cut and sew manufacturing was widely used, with 48% of manufacturing respondents reliant on it for their products, specifically the medium sized businesses, where up to 2.5 million annual unit sales were reported. Cut and sew users reported higher amounts of recycling than fully fashioned counterparts (33%). Natural fibres were more likely to be recycled, along-side regenerated fibres for both cut and sew and fully fashioned products. Seemingly, knitwear companies do not assess the impact of material use, manufacturing, or customer use phase often. Despite 84% of respondents choosing environmentally preferred materials for some or all products, 65% did not assess the environmental or social impact of these materials within their own product development process. 71% did not assess the impact of the customer 'use phase' of the product, and those that did, used informal and internal assessment methods.

Despite the technological developments in 3D Garment Simulation Software the results showed that it was rarely in use, and if it was it did not reduce prototyping quantities. Many prototypes are still created during the knitwear development process due to inaccurate fit. Larger companies reported creating five or more prototypes, which was concerning due to the larger range of new product styles released throughout the year. The calculation and fit issues which result in further prototyping seemingly contribute to the reliance on cut & sew knitwear, as a desired fit is often easier to achieve. Micro entities created fewer prototypes, and those who prototyped more used higher quantities of synthetic fibres.

Seamless knitwear was still scarcely made with only 32% of manufacturing respondents creating it in some way. Those who did manufacture seamlessly created less accessories, cardigans, and outerwear items than those who used fully fashioned or cut and sew processes. Cotton fibres were popular across companies who used cut and sew and fully fashioned methods but not amongst seamless manufacturers. The low uptake of seamless knitwear and garment simulation software confirms there is still a skills gap present within the industry, as previously discovered (Sayer, Wilson and Challis, 2006; Taylor and Townsend, 2014). The questionnaire suggested that the knitwear industry is moving towards an 'on demand' retail model, as 57% of retailing brands offered some made-to-order stock. To support this on-demand approach, the knitwear industry could adopt new digital technologies which offer the opportunity to 3D simulate garments and customise fit for personalised, custom-made clothing.

6. Implications, limitations and future studies

6.1. Implications

The findings in this study offer insight into the knitwear industry's environmentally impactful practices, and the interdependencies of company size, equipment, product range and material usage. The implications of these findings are of significance to knitwear brands as a prompt to adopt innovative design practices, for instance designers could dictate the use of a low waste manufacturing techniques. This investigation also offers the opportunity for machine manufacturers to respond to some of the issues which have arisen. For example, partial cut and sew knitwear was found to be used for jumper necklines with large order quantities, improvements in machinery capabilities to integrate the shaping of necklines in a more cost effectively and timely manner may significantly support the reduction of waste within the sector.

Inaccurate fit was reported to impact the knitwear product development system from initial prototypes through to manufacturing techniques. It can be argued that a more comprehensive understanding of knitted fabric behaviour would go some way in supporting the enhanced prediction of garment fit. Understanding these behaviours and consequently virtually prototyping, may support a reduction in physical prototyping quantities and promote confidence in utilising manufacturing techniques where garments are knitted three dimensionally without the need for cutting.

6.2. Limitations

It was first hoped that case studies could be undertaken at various knitwear companies of varied sizes, however due to the complications within the fashion industry which arose surrounding the COVID-19 pandemic this was unattainable. In-person interviews may have facilitated a more open conversation around the difficulties which surround developing knitwear products however, the questionnaire was designed to be robust, and a mix of data ascertained to provide a holistic overview. In addition, while great lengths were made to attract an even number of micro, small and medium enterprises, this was not possible with 18 micro, eight small, and five medium-sized companies contributing to this research. Again, it is theorised that this imbalance may be partially due to the impact of COVID-19, in such that furloughed staff may have been unavailable to engage with the study, because of limited available resources and challenging times.

6.3. Opportunities

Case studies with on-site observations investigation of company records, and interviews of staff along the supply chain may offer further understanding of the environmental issues within the knitwear manufacturing sector. Future studies surrounding the improvement of garment fit and the understanding of knitwear garments is vital due to their demonstrated direct correlation with waste production. The findings reported in this study have revealed otherwise unknown results around the production of knitwear garments. These findings offer knitwear practitioners intelligence around the industries product development from design and ideation through to retail. Research findings presented here have successfully shown where knitwear designers and manufacturers can reduce their environmental impact.

7. Conclusion

It can be concluded from this study that knitwear SMEs are dynamic, diverse, and innovative. Industry responses inform of material innovations such as pineapple fibre and novel sustainable woollen knitwear products, and the creation of tech driven apparel solutions such as footwear uppers. Further confirmation of the creativity the knitwear industry offers is it's reliance on new conceptual research as the most used design method. Retail offers the knitwear industry a direct opportunity for positive relationships with consumers, where PSSs such as mending schemes and take back initiatives are common. However, it is apparent that the industry is still restricted by issues addressed in the introduction. For instance, it is vital that knitwear designers are aware of their ability to design out certain environmental impacts, especially those incurred during manufacture, as 69% of knitwear designers chose the manufacturing routes of products. Design education must address the systemic issue of waste within manufacturing for knitwear specialists.

The questionnaire also made apparent that the digital skills gap is ever present in the industry today. Seamless knitwear, renowned for its digital complexity is the least used garment production process with few creating small performance wear batches. Virtual prototypes are sparsely applied, despite the advancements in 3D garment simulation programs. These prototypes offer the opportunity to reduce waste and improve efficiency within product development. Larger companies with the capital to invest, often relied on analogue methods and created more prototypes than small and micro counterparts. In general, issues which rely heavily on knit calculation, such as fit, grading, and design flaws are the common cause for the generation of multiple prototypes. Machinery manufacturers and software developers need to improve accuracy to boost its utilisation. Those reliant on digital knit design software are dependent on the re-design of stock garments for the reasons listed above. Reliance on this process is due to the complexity of the design process. Further gaps in software capability are apparent, as participants state that cut and sew methods are essential, otherwise the desired stitch pattern is unachievable. The conflicting stance on sustainability is still obvious, with respondents considering a range of conflicting materials to have positive environmental attributes. It is apparent that the industry is aware of the destructive impact of synthetic fibres on the environment and chooses to use natural fibres readily across the board. Designers had a 'surface level' view of sustainability which is rarely viewed systemically through the supply chain. The assessment of the environmental and social impacts of products and services is low on the industries priorities.

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CRediT authorship contribution statement

Eleanor L. Scott: Conceptualization, Formal analysis, Methodology. **Tracy Bhamra:** Conceptualization, Supervision, Writing – review & editing. **Mazher I. Mohammed:** Writing – review & editing. **Andrew A. Johnson:** Conceptualization, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

References

Battaglia, M., et al., 2014. 'Corporate social responsibility and competitiveness within SMEs of the fashion industry: Evidence from Italy and France'. Sustainability (Switzerland) 6(2), pp. 872–893. Available at: https://doi.org/10.3390/su6020872.

Bevilacqua, M., Ciarapica, F.E., Mazzuto, G., Paciarotti, C., 2014. Environmental analysis of a cotton yarn supply chain. J. Clean. Prod. 82, 154–165. https://doi.org/10.1016/j.jclepro.2014.06.082.

Cassidy, T. (2018) 'Knitwear Design Technology', *Textile and Clothing Design Technology*, (October), pp. 441–461. Available at: https://doi.org/10.1201/9781315156163-16.

Center for Sustainable Fashion and British Fashion Council (2019) 'Fashion & Environment - An Overview of Fashion's Environmental Impact & Opportunities for Action', p. 73. Available at: https://www.britishfashioncouncil.co.uk/uploads/files/1/NEW Fashion and Environment White Paper.pdf.

Choi, W., Kim, Y., Powell, N.B., 2015. An investigation of seam strength and elongation of knitted-neck edges on complete garments by binding-off processes. J. Textile Inst. 106 (3), 334–341. https://doi.org/10.1080/00405000.2014.922243.

Dong, Z., Jiang, G., Huang, G., Cong, H., 2018. A web-based 3D virtual display framework for warp-knitted seamless garment design. IJCST 30 (3), 332–346. https://doi.org/10.1108/IJCST-05-2017-0060.

Earley, R., 2017. Circular Design Futures. Des. J. 20 (4), 421–434. https://doi.org/10.1080/14606925.2017.1328164.

Eckert, C., 2006. Generic and specific process models: Lessons from modelling the knitwear design process. TMCE 2006 (December), 681–692.

Eckert, C., Stacey, M. (1994) 'CAD systems and the division of labour in knitwear design', *Women, Work and Computerization: Breaking Old Boundaries – Building New Forms*. pp. 409–422.

Eckert, Claudia, Stacey, M. (2003) 'Sources of inspiration in industrial practice: The case of knitwear design', *J. Design Res.* 10(3), pp. 250–257. Available at: https://doi.org/10.5101/nbe.v10i3.p250-257.

Eckert, C. (1998) 'The Communication Bottleneck in Knitwear Design: Analysis and Computing Solutions', *Journal of Intelligent and Robotic Systems: Theory and Applications*, 22(3–4), pp. 255–267. Available at: https://doi.org/10.1023/A.

Evans-Mikellis, S. (2011) *Future forms: a methodological investigation for garment shape innovation in knitwear design*. Master of Art and Design. Auckland University of Technology. Available at: http://aut.researchgateway.ac.nz/handle/10292/1395.

Fashion Revolution (2022) *Fashion Transparency Index 2022 Edition*.

House of Commons and Environmental A (2019) *Fixing fashion: Clothing consumption and sustainability*. Available at: https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/1952/full-report.html.

Jose, S., Salim, R., Ammayappan, L., 2016. An Overview on Production, Properties, and Value Addition of Pineapple Leaf Fibers (PALF). J. Nat. Fibers 13 (3), 362–373.

Kant Hvass, K., Pedersen, E.R.G., 2019. Toward circular economy of fashion: Experiences from a brand's product take-back initiative. JFMM 23 (3), 345–365. https://doi.org/10.1108/JFMM-04-2018-0059.

Kilinc, N. and Bor Kocoaman, A. (2019) 'Comparison of Try-On Over Actual and Virtual Mannequins for Knitwear Garments', *The Turkish Online Journal of Design Art and Communication*, 9(3), pp. 367–375. Available at: https://doi.org/10.7456/10903100.

Ma, Y. and Lamar, T.A.M. (2013) 'Three-dimensional Shaping for Knitted Garments', *Research Journal of Textile and Apparel*, 17(3), pp. 128–139. Available at: https://doi.org/10.1108/RJTA-17-03-2013-B013.

McKinsey & Company (2022) *The State of Fashion 2022*.

Power, E.J., Almond, K., 2019. Comparative study of calculated and actual dimensions in shaped weft-knitwear. Int. J. Fashion Design Technol. Educ. 12 (2), 225–234. https://doi.org/10.1080/17543266.2019.1573439.

Quantis (2018) 'Measuring Fashion 2018: Environmental Impact of the Global Apparel and Footwear Industries Study Full report and methodological considerations. Available at: https://quantis-intl.com/measuring-fashion-report-2018/.

Salvador Cesa, F., Turra, A., Baruque-Ramos, J., 2017. Synthetic fibers as microplastics in the marine environment: A review from textile perspective with a focus on domestic washings. Sci. Total Environ. 598, 1116–1129. https://doi.org/10.1016/j.scitotenv.2017.04.172.

Sayer, K., Wilson, J., Challis, S., 2006. Seamless Knitwear - the Design Skills Gap. Des. J. 9 (2), 39–51. https://doi.org/10.2752/146069206789377113.

Sneddon, J.N., Soutar, G.N. and Lee, J.A. (2014) 'Exploring wool apparel consumers' ethical concerns and preferences', *Journal of Fashion Marketing and Management*, pp. 169–186. Available at: https://doi.org/10.1108/JFMM-03-2013-0039.

Taylor, J., Townsend, K., 2014. Reprogramming the hand: Bridging the craft skills gap in 3D/digital fashion knitwear design. Craft Res. 5 (2), 155–174. https://doi.org/10.1386/crre.5.2.155_1.

Zhou, W. (2019) *Virtual Fitting of Personalized Knitwear*.