Journal of Cleaner Production 286 (2021) 125498

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Demystifying process-level scalability challenges in fashion remanufacturing: An interdependence perspective

Rudrajeet Pal [a, *], Yasaman Samie [b, 1], Armaghan Chizaryfard [c, d, 1]

[a] Swedish School of Textiles, Department of Business Administration & Textile Management, University of Borås, Allegatan 1, 501 90, Borås, Sweden
[b] Department of Fashion and Textiles, RMIT University, 25 Dawson St, Brunswick, VIC, 3056, Australia
[c] Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Via Lambruschini, 20156, Milan, Italy
[d] Department of Industrial Economics and Management, KTH Royal Institute of Technology, Lindstedtsvägen 30, 100 44, Stockholm, Sweden

ARTICLE INFO

Article history:
Received 20 February 2020
Received in revised form
16 October 2020
Accepted 8 December 2020
Available online 10 December 2020

Handling editor. Yutao Wang

Keywords:
Remanufacturing
Upcycling
Fashion
Scale
Process interdependence
Circular economy

ABSTRACT

The purpose of this paper is to determine how process-level challenges can be solved in order improve scalability of fashion remanufacturing. In order to do so, and prescribe solutions, the paper first conducts a systematic literature review to reveal three categories of process-level challenges that are related to sourcing of input material, process throughput time, and skillset requirement. These categories further guided us in conducting case study with a Swedish charity-owned fashion remanufacturer for exploring how the challenges are addressed and solved in order to achieve process-level scalability. First, our study reveals a systematized approach to determine product-process categories defined by production volume and degree of remanufacturing. Second, by exploring the process-level challenges of six different remanufactured product groups in the case study organization we identify process-level requirements for scalability, and challenges when these are unmet. The findings show that in fashion remanufacturing (particularly disassembly and reassembly), low degree of coupling, high level of formalization of activities and low skill specificity can be ways to attain process-level scalability. Overall, this highlights the need to build lower interdependence between disassembly and reassembly during fashion remanufacturing.

1. Introduction

Global fashion consumption has nearly doubled since 2000 largely due to the rapid expansion of fast fashion (Pulse of Fashion Industry, 2017). This has not only resulted in nearly doubling the sales of clothing from $1 trillion between 2002 and 2015 (projected to rise to $2.1 trillion by 2025), but also has increased fashion waste to about 91 million tons (in 2015), i.e. roughly 17.5 kg per capita (ibid.). Consequently, the potential to harm the environment has risen as well (Dissanayake and Sinha, 2015). It is projected that rise in clothing consumption will increase the water consumption, energy usage, and waste creation by 50%, 63%, and 62% respectively by 2030 (Pulse of Fashion Industry, 2017).

In this context, remanufacturing can play a vital role in the fashion industry for extending product use life, improving resource and energy efficiencies and gain circularity by counteracting planned and premature obsolescence (Dissanayake and Sinha, 2015; Singh et al., 2019). For instance, Woolridge et al. (2006) assert that for every kilogram of virgin cotton (and polyester) being replaced by used clothes (i.e. either second-hand or redesigned or upcycled) almost 65 kWh (and 90 kWh) energy is saved. Additionally, such circularity-based business models place lesser demand for virgin fibres and generate lesser effluents from industrial conversion processes such as dyeing (Dissanayake and Sinha, 2015). Consequently, remanufacturing in the context of circular economy can deliver in most conditions lower eco-costs of pollution, as already evidenced in other industrial sectors such as automotive and machine tools where it has been implemented industrially on a larger scale (see e.g. Seitz et al., 2006; Li et al., 2015; Lage et al., 2016; Casper and Sundin, 2018).

In addition to these eco-benefits, used clothes upgraded through remanufacturing, currently practiced as redesign or upcycling, i.e. replacing few panels of a garment with new ones etc., may provide new look, aesthetics and customer value (Keith and

* Corresponding author.
E-mail addresses: rudrajeet.pal@hb.se (R. Pal), yassie.samie@rmit.edu.au (Y. Samie), armaghan.chizayfard@indek.kth.se, armaghan.chizaryfard@polimi.it (A. Chizaryfard).

[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.jclepro.2020.125498
0959-6526/

Silies, 2015; Han et al., 2017; Pal and Gander, 2018). This has encouraged many fashion designers to undertake remanufacturing – primarily as redesign or upcycling – in their businesses as a new opportunity towards circular economy. However, what fundamentally differentiates fashion remanufacturing from redesign or upcycling beyond differences in market opportunity – in terms of product end use or function, consumer preference and need for warranty – is the degree of process-level industrialization in order to attain scale (Dissanayake and Sinha 2015; Singh et al., 2019). Scalability, in this context, refers to the ability to carry out industrial processes preferably in a "factory" environment with certain degrees of reproducibility to attain high volume (Goodall et al., 2014; He, 2015).

Although the market opportunity for remanufactured products seems promising, there lies huge uncertainty in the remanufacturer's internal processes leading to a number of process-level challenges, defined in terms of quantities and timing of returns, recovery time, cost, product quality and upgradability (Ferguson, 2009; Kurilova-Palisaitiene et al., 2018). Many of these process-level challenges, such as those related to difficulty in sourcing sufficient and appropriate quality of used materials, time-consuming processes, and lack of specialist skills, equipment and tools, currently hinder industrial scalability of fashion remanufacturing, and thus in attaining its full potential (Dissanayake and Sinha, 2015; Pal and Gander, 2018; Singh et al., 2019). Additionally, specific to fashion remanufacturing, the challenge is that garments are conventionally non-modular in product architecture that makes dis- and re-assembly processes far less efficient and more time-consuming compared to products such as mobile phones or computers where components are easier to separate. Overall as a consequence, of lack of scalability, fashion remanufacturing today is practiced mostly as craft or in pilot scale, described as redesign or upcycling (Young et al., 2004; Han et al., 2017) and not as remanufacturing. This highlights the importance of exploring scalability challenges and solutions in the fashion remanufacturing. Given this, the purpose of the paper is to determine *how process-level challenges can be solved in order to improve scalability of fashion remanufacturing*.

The remaining paper is organized as follows: first a conceptual background is provided on remanufacturing in general and fashion remanufacturing in particular. Next, a two-stage research methodology comprising of systematic literature review (SLR) and in-depth embedded case study is presented, followed by presentation of the findings. Finally, we provide analytical interpretation of the case findings from an interdependence perspective to draw relevant conclusions.

2. Conceptual background

2.1. Remanufacturing in circular economy context

Remanufacturing can be defined as an industrial process to restore the core part of end-of-use products as it passes through a series of steps, such as inspection, disassembly, part replacement/refurbishment, cleaning, reassembly, and testing to ensure meeting desired product standards (Goodall et al., 2014; Lieder and Rashid, 2016; Kurilova-Palisaitiene et al., 2018). In sectors such as automotive and machine tools, remanufacturing is largely related to efficient reclamation of the core parts, receiving product design information and reducing uncertainty in the timing and quantity of return, by predominantly using hybrid manufacturing/remanufacturing systems (Aras et al., 2006).

In context to circular economy, remanufacturing ensures not only recovery of end-of-use products but also in adding value (Charter and Gray, 2008; Gallo et al., 2012). According to Nasr and Thurston (2006), remanufacturing is typically a more efficient mean of material recirculation than recycling as it retains higher energy associated with the original conversion of raw materials to finished product. By replacing the use of virgin materials, remanufacturing can be recognized as one of the best methods for sustainable production, managing wastes and eco-efficient value creation (Krystofik et al., 2015; Vogtlander et al., 2017). Wen-hui et al. (2011) state that the quality of a remanufactured product and its performance is not less than that of a new product, by considering the fact that it has lower eco-costs, shorter production cycle and processing time, and lesser negative impacts on the environment compared to the production of new products. Though high process cost is highlighted as a recurring challenge in remanufacturing, mainly due to high labour intensity of various manual operations involved with reassembly and disassembly (e.g. Jiang et al., 2016; Oh and Behdad, 2017), in certain developing economies such as China remanufacturing industry has enjoyed higher competitiveness due to low cost (Wen-hui et al., 2011). Moreover, Vogtlander et al. (2017) shows by applying a model for eco-efficient value creation (EVC) that combines analyses of costs, market value and eco-costs, remanufacturing of products can deliver lower eco-costs of materials depletion and pollution, thus positive cost-benefit.

The concept of remanufacturing is often closely associated with other recovery options such as refurbishment, reconditioning and repair. Although they share various commonalities in the process with remanufacturing, the fundamental difference lies in terms of warranty, final product performance and positioning in the material flow loop (Charter and Gray, 2008; Gallo et al., 2012). For instance, reconditioning returns a product functionally to almost same as new product condition but unlike remanufacturing it might not necessarily provide warranty and the process might not include disassembly and cleaning of all product parts (Charter and Gray, 2008). Moreover, it can be stated that remanufacturing is a process, i.e. comprising of a set of interlinked activities, rather than a single step as like repair or reconditioning, aimed at restoring the performance of a product (Gallo et al., 2012).

2.2. Fashion remanufacturing process

In fashion context, remanufacturing aims at remaking used clothes so that the product at least equals to newly manufactured garments in terms of quality or customer value. Dissanayake and Sinha (2015) define remanufactured fashion as *"fashion clothing that is constructed by using reclaimed fabrics, which can be either post-industrial or post-consumer waste or a combination of both"*. This way, the core part, i.e. the fabric of the end-of-use garments is reclaimed and refurbished. Consumer's willingness-to-pay for remanufactured fashion products to that of new ones, expressed as a discount factor, is often >1 (Kleber et al., 2018).

The concept of fashion remanufacturing became more popular at the beginning of 21st century among sustainability-oriented fashion designers and entrepreneurs in order to develop sustainable collections out of post-consumer textile and clothing waste (Gwilt and Rissanen, 2011; Niinimäki and Hassi, 2011). In general, extant literature highlights the process of remanufacturing comprises of: (i) efficient reverse logistics and (ii) product development (Charter and Gray, 2008; Wen-hui et al., 2011). Fashion reverse logistics starts with retrieving the discarded garments from various sources, such as charities, end consumers, retailers, waste collectors and sorting facilities. This continues further with the sorting of the collected items on the basis of a number of criteria, like fabric type, colour, and product category (Dissanayake and Sinha, 2015). Followed by an optional cleaning procedure the sorted items are ready for remanufacturing, i.e. when the product development process initiates. Fashion reverse logistics also include final distribution, marketing and retailing of the remanufactured items. Dissanayake and Sinha (2015) highlight five steps underlying fashion remanufacturing product development:

1. Trend and material analysis,
2. Concept development, starting with manual disassembly of the garments by unpicking the seamed threads or cutting along the seams, followed by design development often using either draping techniques or pattern cutting,
3. Sample preparation to showcase a collection for potential retail buyers,
4. Pattern development and single-ply cutting performed manually from the flat fabrics, and adjustments being made during cutting due to fabric restrictions, and
5. Final assembly as an individual/whole garment.

From a decision-making perspective, disassembly and reassembly are based on the creative eye of the designer and rationality of the remanufacturer (Janigo et al., 2017), thus highlighting the presence of rule-of-thumb based heuristics.

3. Methodology

To fulfil the purpose a two-stage methodology is adopted. A systematic literature review (SLR) provides the starting point for identifying the process-level challenges, and prescribed solutions, specific to fashion remanufacturing, particularly because the current academic literature still remains quite fragmented on these topics (Singh et al., 2019). This is followed by an in-depth case study to explore scalability solutions from practice.

3.1. Systematic literature review (SLR)

Search was conducted on Scopus database, with search string/combination (“remanufact*" OR “upcycl*" OR “remak*" OR “redesign”) AND (“textile” OR “cloth*" OR “apparel” OR “fashion”) AND (“challeng*" OR “barrier” OR “problem” OR “limitation”) in the title, abstract and keywords. The search was limited to retrieving only journal articles written in English, and those falling under the subject areas of business and economics, social science or environmental science, thus resulting in a total of 45 papers. After reading the abstracts and looking for the relevance in the content in terms of addressing remanufacturing challenges at the process-level, only 8 papers were selected which further reduced to a final list of 4 after full reading (see Appendix 1, column 3).

Given this relative dearth in literature on process-level challenges found in context to fashion remanufacturing, the search was broadened to cover entire remanufacturing literature, with string/combination “remanufact*" in the title AND “challeng*" in the title, abstract and keywords, thus retrieving 74 papers. With the same restrictions put in the search as prescribed above, and after abstract and full paper readings, 16 papers were found relevant. Most of these papers (14 out of 16) were published 2015 onwards while Journal of Cleaner Production was the most popular outlet (publishing 4 of them). Further topical description of these papers can be found in Appendix 1 (column 2).

3.2. Case study approach

Given the general lack of conceptual and empirical attention to explore process scalability in remanufacturing, and more specifically in fashion industry, the choice of conducting an explorative case study is pertinent for developing novel theoretical insights that are firmly rooted in practice (Langley and Abdallah, 2011). Although our paper involves an initial consultation of existing literature, through an SLR, in order to reveal the categories of process-level challenges, we cannot reveal direct connection to the solutions prescribed, and more importantly not specific to fashion remanufacturing. In line with inductive reasoning, this makes it crucial to consult an observed case for understanding how the challenges are managed, and scalability solutions are prescribed, thus rigorously analyse data and express in relation to current theory. We follow an inductive approach in line with Gioia et al. (2013), where an appropriate choice of case context sufficiently reveals in-depth understanding of the complex phenomenon, i.e. in here, process-level challenges to fashion remanufacturing scalability, and at the same time explores real-world solutions. This approach also fits our research purpose well, given the relatively broad focus on scalability challenges and solutions proposed in existing literature (e.g. Kurilova-Palisaitiene et al., 2018).

3.2.1. Case selection and description

The fashion remanufacturing cases are embedded in a Swedish fashion remanufacturer (referred as *RemCo* from now on). *RemCo* is over 15 years old, and is a part of one of Sweden’s largest charity organization. It currently produces over 2500 remanufactured products per year across 25 different varieties at its 3 mini-factories in Stockholm, which is sold via one store. Products include fashion items, like jackets, shirts, trousers, as well as accessories, and can be classified as unisex, uni-size and freestyle, as the style, design and the patterns remains the same throughout the year with slight adjustments are being made in the material, fabrics and colour palette. These remanufactured products as cases are typically categorized in *RemCo* into three categories depending upon the degree of remanufacturing:

- “Sewn from scratch” type when products are first fully-disassembled, i.e. totally opened up and un-seamed, and turned to flat fabric. The smaller pieces of fully-disassembled products are then sewn together to make wider and longer fabric strips called “snakes” from which an entirely new fashion product is produced by making completely new patterns. Fig. 1 depicts how standard-sized “snakes” are formed from two used garments, and then a completely new garment is assembled.
- “Cut, add and put-together” type when products are semi-disassembled and semi-reassembled. Disassembly is limited to few major or minor cuts at specific predetermined locations. Depending on the design and style of the new products, the old garments that have already been cut into major pieces are stitched together. Fig. 2 shows an example of remanufacturing a narrow shirt made out of three garments – a yellow base garment and two additional ones in blue and green.
- “Minor-value adding” type when products are not cut or disassembled, instead remanufacturing is conducted only through certain value-added recoupling activities, e.g. stitching, printing, embroidering and patching etc. Fig. 3 shows the patchwork on a jeans packet without disassembling it, and additionally other possible options are sketched.

In line with the approach prescribed by Gioia et al. (2013), these cases as representative of variations in product-process structure provides us deep explanation of the scalability challenges and solutions in fashion remanufacturing context, thus aiming to increase richness and relevance for theory building.

These products have different levels of production complexities, in terms of input volume and acquisition difficulties, requirements of manual labour intensity and skill for construction, and degrees of disassembly and reassembly. This makes *RemCo*’s fashion remanufacturing and its planning interesting from a scalability

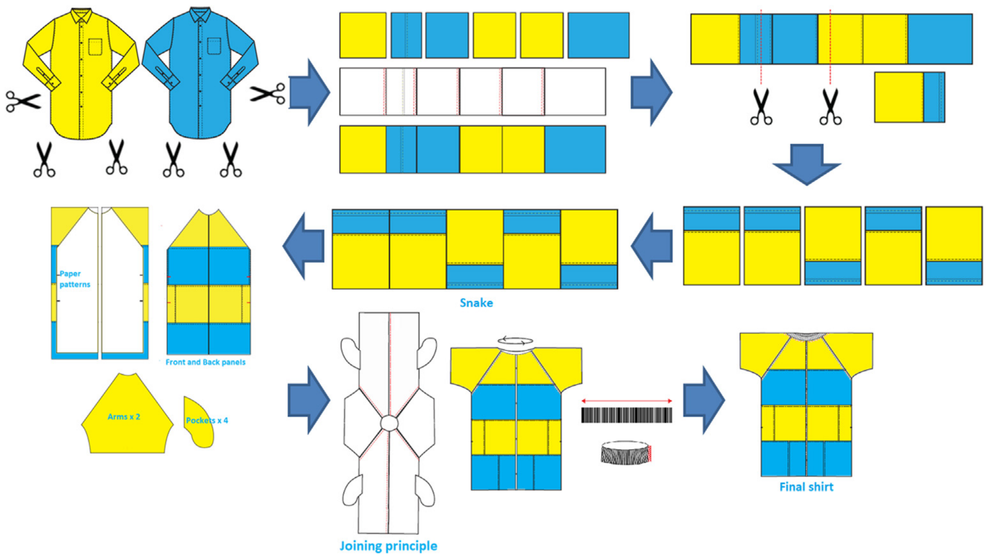

Fig. 1. Representative "Sewn from scratch" type of remanufactured products.

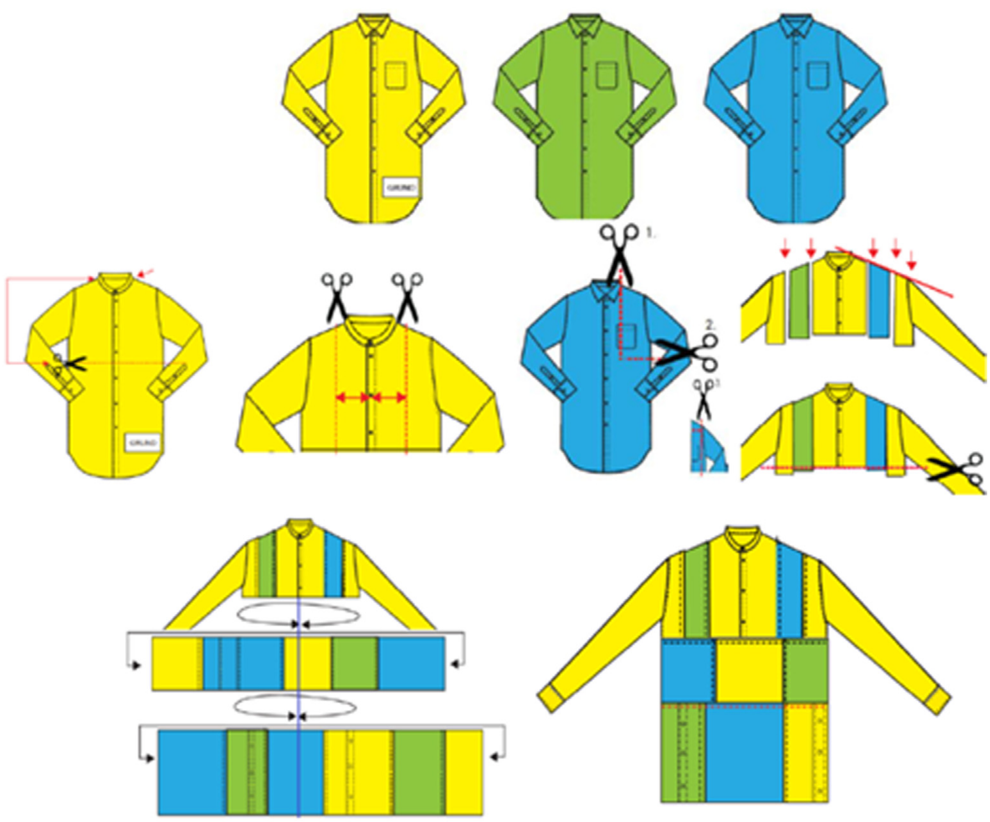

Fig. 2. Representative "Cut, add and put-together" type of remanufactured products.

perspective, as no 'one-size' approach 'fits-for-all', thus providing a rich source of evidences required for explorative case study (Flyvbjerg, 2006). For instance, *RemCo* has many products that are "sewn from scratch" from the material that are made from meters of fabric formed by sewing patches of cut fabrics, or by "cutting, adding and putting together" multiple garments. These categories require different resources and capabilities, key design elements, decision criteria and process level interdependencies depending upon the required degree of remanufacturing.

3.2.2. Data collection and analysis

For conducting this case study, data was collected in a number of ways, primarily through on-site observations. Two researchers spent six weeks in total at *RemCo*'s facilities where they observed the product development and production stages constituting the remanufacturing process. These observations were mainly documented in formats, such as visual process maps and photographs/videos. Visual data captured in the form of photographs and videos (~1.1 GB) recorded different activities and operations that were

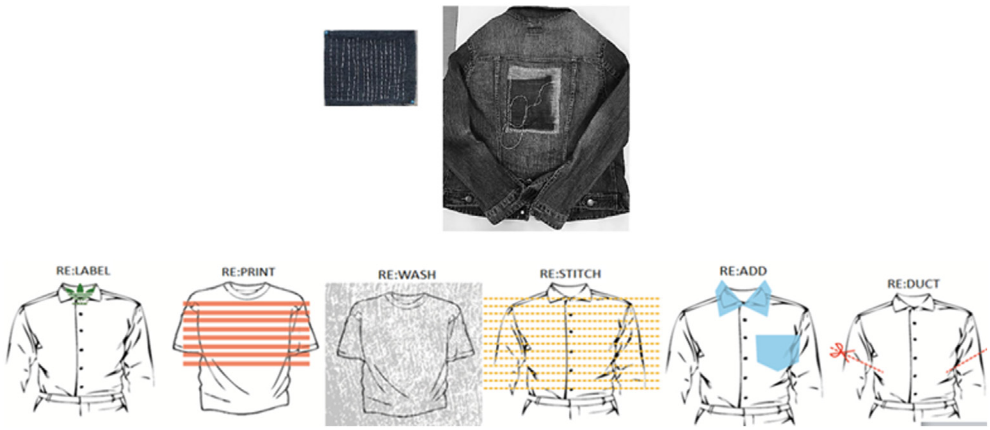

Fig. 3. Representative “Minor-value adding” type of remanufactured products.

conducted on the factory floor at various intervals. These served as a rich source of evidential data for formulating and depicting the remanufacturing processes, i.e. how the workers are involved in finding the right garments to disassemble, how garments are unseamed, how the reassembly are processes organized etc. Additionally several charts and images were also gathered, e.g. product construction diagrams (Figs. 1–3), instruction manuals and production process plans (Fig. 4).

During this process of observation, informal conservations were conducted randomly and on a daily basis with the key personnel working with remanufacturing, such as designers, seamstresses and pattern makers. Account of these “talks” or conversations were kept only as short, factual, hand-written notes in the field diary (Swain and Spire, 2020) in the spirit of clarifying some of the observations that were made by the researchers during the fieldwork to get understanding of *RemCo*’s activities. These conversations were kept informal as the respondents only had knowledge of limited number of activities, i.e. of what they are associated with. Furthermore, they had limited reflective and decision-making power as their work was mostly “blue-collar” in nature. However, in order to get a more complete and strategic view on *RemCo*’s product groups, process structure, underlying challenges and scalability solutions, 3 semi-structured interviews were conducted with the lead designer (and originator) of *RemCo* who had the best and most complete information of all the activities. The lead designer possessed the creative vision and foresight related to current situation and future requirements at *RemCo* connected to advancing the scalability of fashion remanufacturing. Appendix 2 includes a key set of questions that were asked, however for homogeneity in recording and interpreting the data these were also documented as field notes.

For data analysis, multiple data types (interview-based field notes, visual recordings like photos/videos) were aggregated and utilized collectively to generate understanding of the challenges and solutions (see section 5). For instance, the visual representations of the products/processes (Figs. 1–4) provided first-hand information of the remanufacturing processes which then were rechecked or verified through the qualitative information gathered via interviews and verbal communication with the respondents. Such process data analysis involving visual mapping strategy (Langley, 1999), and serves as a good way to develop mental models and knowhow in an explorative manner considering that formalized approaches are yet less available in this context. By doing so, the research objective of “fact-finding” is complemented by “good” theory building (Wacker, 1998), in context to finding solutions to process-level challenges in fashion remanufacturing.

4. Process-level challenges and solutions in remanufacturing: from SLR

In line with the six process-level challenges in remanufacturing defined by Kurilova-Palisaitiene et al. (2018), appendix 1 provides a detailed mapping of these challenges (in column 2) found through SLR, and then draws connection to those found in context to fashion remanufacturing (in column 3). Additionally, the prescribed solutions found through SLR are also summarized (in columns 5 and 6). The remanufacturing process-level challenge categories as identified through SLR (in column 4), namely those related to sourcing of input material, processing time, and skillset requirement, forms the basis of further elaboration below, and for subsequent case study exploration in section 5.

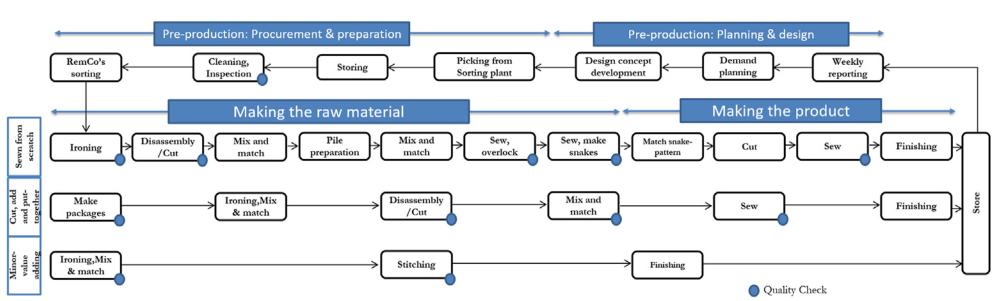

Fig. 4. Fashion remanufacturing process mapping at *RemCo*.

4.1. Sourcing of input material-related

Volume and quality of incoming product core are the main challenges related to proper acquisition and management of material for remanufacturing. When it comes to volume, several factors such as supply shortage, stochastic and unreliable returns, and recovery uncertainty are revealed through SLR (e.g. Casper and Sundin, 2018). Quality variation of the incoming material and lack of standardized quality control/inspection is also a major challenge (e.g. Priyono and Idris, 2018). For fashion remanufacturing, similar challenges related to sourcing input material reverberate, those related mainly to variability of the timing and quantity of consumer returns, and in their quality. Ensuring a predictable and stable flow of reused materials, mainly second-hand garments from different post-consumer waste streams is a challenge for remanufacturing businesses. In terms of quality, fashion remanufacturers largely rely on collection of post-consumer material, e.g. fast fashion items, which leads to uncertainty and unreliability in the quality of the collected and recovered material (Singh et al., 2019), due to high wear and tear. It is comprehended that remanufacturing using post-industrial (or pre-consumer) waste, could provide more consistent quality and reliable supply as source materials (Han et al., 2017).

This pinpoints the need for internal integration and collaboration (Golinska-Dawson et al., 2015; Jiang et al., 2016; Kalverkamp and Raabe, 2018; Kurilova-Palisaitiene et al., 2018). Internal coordination, e.g. through vertical integration, can increase component specificity, standardize operations, or create integrated quality evaluation, that can support development of a standard level in remanufactured products and to scale up the production. Collaboration, on the other hand, by diversifying the supply sources through networking can ensure efficient reverse flow of material. Such collaborative networks can be perceived in fashion context, e.g. between the remanufacturers and textile recyclers (sorter and collector), together with local craft entrepreneurs, in order to guarantee required standards and volumes (Dissanayake and Sinha, 2015). However, such collaboration operates mainly at the system-level (Kurilova-Palisaitiene et al., 2018), beyond the remanufacturer's process-level solutions.

4.2. Process throughput time-related

Operational challenges in terms of randomness in timing and long throughput time (Franke et al., 2006; Golinska-Dawson et al., 2015; Lage and Godinho, 2016; Priyono and Idris, 2018; Li et al., 2019), were found to be main ones related to remanufacturing. These further result in the capacity planning and task levelling difficult due to the inherent variability and low reliability in the remanufacturing processes. On similar lines, fashion remanufacturing processes have been reported to be time-consuming and random, thus difficult to plan capacity and schedule. For instance, Dissanayake and Sinha (2015) explain how variable and unpredictable processing time makes it difficult to establish control over garment disassembly and cutting during remanufacturing.

Three categories of solutions are prescribed to address these challenges. Firstly, automation of remanufacturing process technologies, e.g. for disassembly, pattern cutting etc. can reduce the throughput time. Secondly, improved routing during remanufacturing tasks, either by improving facility layout plan, or by creating aggregated planning and scheduling for levelling capacity, have been prescribed by some authors (e.g. Lage and Godinho, 2016; Kwak, 2018; Li et al., 2019). In fashion remanufacturing, such aspects are highlighted by using flexible or modular manufacturing. Finally, role of support systems, such as visual tools and standard instructions are also relevant for reducing process variability and complexity.

4.3. Skillset requirement-related

In general, remanufacturing operations such as disassembly are conducted manually, which demands more time and are subjected to higher human error. Further, as remanufacturing processes are highly uncertain in terms of level, sequence, methods, and quality standards, the remanufacturer's skills and experience plays a vital role. Literature has highlighted the lack of knowledge and skills (Lie et al., 2018; Priyono and Idris, 2018) in monitoring product-process reliability and quality, and subsequently standardize these aspects, which is also prominent in fashion remanufacturing (e.g. Singh et al., 2019).

Prescribed solutions highlight the role of increasing qualification of the remanufacturers (Casper and Sundin, 2018; Kurilova-Palisaitiene et al., 2018), which can be achieved through employee cross-training, team-work and learning through problem solving. In fashion remanufacturing (Dissanayake and Sinha, 2015; Han et al., 2017), designers' creative capacity and technical capabilities together with tacit knowledge have a crucial role in increasing fashion remanufacturing production efficiency and volume. This invokes more centralized role of design-makers. Along with, technology uptake, such as application of innovative design and product development approaches help to remove the complexity and need for manual interventions in fashion remanufacturing process.

5. Case study findings

The case study reveals a systematized approach to organize fashion remanufacturing process at *RemCo*, compared to rule-of-thumb heuristics. *RemCo*'s remanufacturing process largely serves as a foundation for understanding how the three categories of process-level scalability challenges, i.e. sourcing of input material-, process throughput time-, and skillset requirement-related are solved.

5.1. Fashion remanufacturing product-process categories at RemCo

RemCo's product categories are defined on the basis of its production volume. As in fashion remanufacturing standardization can be difficult to achieve due to lack of repeatability of the incoming material, the production order volumes are considerably small compared to conventional apparel production, yet it is significantly higher compared to redesign and upcycling pilots. Based on many years of remanufacturing experience, *RemCo* has heuristically determined three categories to define yearly production volume for each of its products; these are:

- *Mass volume*, referring to yearly production $V \geq 100$ items,
- *Standard volume*, if $10 = V < 100$, and
- *Limited volume*, if $V < 10$.

Process mapping (Fig. 4) revealed that the pre-production stage at *RemCo* starts with monthly demand order planning evaluated based on the previous month's sales report from the store. In fact, the sales report is availed on a weekly basis, based on which the input materials are picked from the sorted piles of used clothes in the sorting facility. Typically, these items are the crème of the sorted used clothes. In case of continuous availability of the requisite input material, the clothes are directly send to the preparation stage, where all the used clothes are washed and inspected before being approved of entering the remanufacturing process. In case the input material is hard to find, there is an intermediate storage to pile-up adequate stock before being send for washing and inspection. Cleaning and inspection are thus mandatory for every input material entering the remanufacturing process. The weekly sales status also serves as an information to determine how many items, and which ones, from the storage sections would be disassembled and reassembled.

After cleaning and inspection stages, the clothes are ready for the first stage of disassembly and raw material preparation. At this stage, the decision taken is whether a garment will undergo full-, semi- or no-disassembly, and this is based on the requirements specified in the product construction sheet. Typically, such decisions are taken by the lead designer in the team due to the need for judging the suitability of the material based quality and redesign-ability. Such clinical cognition of the foreseeable remanufactured products is crucial in order to segregate the input raw materials in different shelves of the sorting section, by taking into consideration different aspects, such as design, technical parameters like fabric quality, and stock repeatability. Intermediate inventories are also maintained in a storage section in various semi-processed forms, such as patches, piles, overlocked pieces, cut patterns and snakes.

Further on-site observation revealed that in order to make the products three generic remanufacturing process structures are followed at *RemCo*, which are largely determined by the degree of disassembly and reassembly required during remanufacturing. At *Remco* these are indicated by the number of activities constituting the two remanufacturing sub-processes − disassembly and reassembly. Here, degree of disassembly indicates the extent by which the input material (i.e. the initial fashion product) goes through disassembly operations in order to be ready for remanufacturing, while the degree of reassembly refers to the extent of final remanufacturing conducted for the production of a remade fashion product. In general, fully-reassembled items are mostly produced out of fully-disassembled products. Similarly, semi-disassembled products are processed into semi-reassembled new items. Also it was observed that the fashion products which are not disassembled are often the items that undergo minor value addition. Thus the three process structures observed at *RemCo* are represented by the different remanufactured product cases, i.e. “sewn from scratch”, “cut, add and put-together” and “minor-value adding” types, categorized on the basis of the degree of remanufacturing as shown in Figs. 1−3. Typically the number of steps also varies: for full remanufacturing, number of process steps N is ≥ 8, for semi remanufacturing ($5 = N < 8$), and for minor remanufacturing ($4 = N$), as comparatively shown in Fig. 4.

The “sewn from scratch” process starts by sorting out the good quality items that are ready to be ironed and cut. Manual single ply cutting is done using specific rectangular pattern pieces to make standard cut panels (27×16.5 cm^2 and 27×10 cm^2), which are mix-and-matched, based on the colour, pattern, texture, fabric weight in order to ensure that the pieces to be joined are compatible. Once the combinations are approved these are overlock stitched together into flat fabrics or “snakes”. However, “snakes” are not prepared separately for each product but rather meters of flat fabrics are first prepared and later the products are produced out of them. Thus these “snakes” are always made in length more than 1 m and width of either 40 cm or 80 cm. Followed by overlocking the cut panels quality check is done, and in case of no defect or error, the pieces are sewn together thus resulting in “snakes”. Subsequently paper patterns are placed on top of the “snakes” to check the measurements, and if the patterns and the snake matches in terms of length and width, the patterns are cut and sewn together. At *Remco* such routinization has resulted in keeping small inventories, i.e. about 300 cut pieces as well as 3−4 “snakes” to continuously meet the store orders.

In case of “cut, add and put-together” products, the process starts with making packages of a base garment and 2-3 additional ones. These garments are first, sorted and selected by the lead designer usually based on their size, style, colour and fabric material so that mix-and-match later is easy. The selected garments are then hung next to each other for “package making”. The disassembly starts with manual single piece cutting of the garments as per instruction in the construction sheet, and is at predetermined positions as shown in Fig. 2. Next, the cut garments are ironed and are matched once more in terms of their sizes as well as the quality of cut, before finally the pieces are sewn together. Sewing can be complicated, which includes sewing of the top part of the garment to the middle and subsequently the bottom part.

Out of the “minor-value adding” products, most common are the patched ones, i.e. patched t-shirt or denim jacket. The process of sorting and selection of the right item is done by the lead designer based on durability, style, fabric type etc. followed by matching the decorative patches in terms of size and style with the base garment. The next step is stitching the decorative patches on the garment either, on stitching or embroidery machines, or in some occasions are hand-stitched.

5.2. Evaluating RemCo’s fashion remanufacturing process-level scalability challenges for different product groups

Explorative mapping of the remanufactured products onto the product-process categories reveals 6 distinct groups of products that are most regularly made at *RemCo*’s facilities, as shown in Table 1. Considering that the supply and operational capacity requirements, i.e. input material volume, throughput time demands and remanufacturing skillset (Dissanayake and Sinha 2015), are vital to determine the process-level scalability of remanufacturing, the challenges were noticed to be surfacing out when these requirements were unmet.

- **Input material volume (I_v):** is determined by the ease or difficulty in sourcing or accessing the appropriate material, mostly second-hand garments for each product group and not at the aggregated level. Depending on several factors such as fabric material, weave construction, size and style, I_v (in kgs per month) varies. Additionally, if the input material fails to satisfy the key requirements laid during quality checks that happen after several steps of remanufacturing operations, as depicted in Fig. 4, it can go back to the sorting plant. *RemCo* classifies I_v into: *Easy* ($I_v > 100$ kgs), when there is a constant uptake of the input materials for remanufacturing, *Semi Easy* ($10 < I_v < 100$ kgs), when the material is relatively easy to find yet not necessarily appropriate for remanufacturing, and *Hard* ($10 \leq I_v$), when it is hard to find material often due to stringent quality requirements. Thus final I_v for remanufacturing process is determined by a number of factors, such as variety, quality, compatibility.
- **Throughput time demand (TD):** indicates how time-consuming the remanufacturing processes are for each product group. At *RemCo* this is categorized as *High*, if TD is more than two days, *Intermediate* if between one and two days, while *Low* if lesser than 24 h. TD also includes non-value adding time (e.g. waiting time between dis- and re-assembly stages) that is typically longer with higher level of disassembly.
- **Skillset requirement (S):** At *RemCo* this is normally decided in terms of the experience gained by the workers, e.g. tailors, in terms of weeks of training received before joining the main remanufacturing floor. *High skillset* refers to when experienced tailors who have been trained for more than 8 weeks are demanded to do remanufacturing. *Moderate skillset* refers to involvement of workers who haven’t had any experience in

Table 1
Mapping the main product groups.

Group	Product examples	Product-process categories	I_v (in kgs per month)	TD (in days)	S (in months)
1	Jacket, coat	Limited Volume + "Sewn from scratch"	Easy (I_v > 100)	High[a] (TD > 2)	High[a] (S > 2)
2	Narrow shirt, trousers, wide-knitted sweater	Standard Volume + "Sewn from scratch"	Easy (I_v > 100)	High[a] (TD > 2)	Moderate (1 < S < 2)
3	Mega long shirt, kimono, knitted jumper	Standard Volume + "Cut, add and put-together"	Hard[a] (10<I_v)	High[a] (TD > 2)	Moderate (1 < S < 2)
4	50/50 shirt, long shirt	Mass Volume + "Cut, add and put-together"	Easy (I_v > 100)	Intermediate (1 < TD < 2)	Moderate (1 < S < 2)
5	Denim jackets, patched denim jeans	Standard Volume + "Minor-value adding"	Easy (I_v > 100)	High[a] (TD > 2)	Low (S > 1)
6	T-shirt and college jumpers with patches	Mass Volume + "Minor-value adding"	Easy (I_v > 100)	Intermediate (1 < TD < 2)	Moderate (1 < S < 2)

NOTE.
[a] Highlights the pain points where the key process-level scalability challenges are located.

sewing in the past, but have been under training for a period of 1–2 months. *Low skillset* indicate that the remanufacturing can be conducted by involving workers who have been under training for less than a month. During interview, the lead designer indicated that not necessarily all the trainees manage to develop same level of skills over a given time however trainees mostly are proven to gain relatively high level of sewing and cutting skills over a period of 2 months.

5.3. Summary of the process-level scalability challenges

The following can be concluded from the *RemCo* case study:

- Product groups 1 and 2, made through full remanufacturing, demand both higher TD and S. These constraints restrict the production volume even though sourcing is not a concern with continuously available materials.
- The semi-remanufactured products (Groups 3 and 4), require comparatively lower TD and S; thus higher production volume could be attained for such products. However, reassembly in product group 3 require adding 2/3 garment parts on the base garments, and producing such products require careful mix-and-match of different styles, materials, fabric textures, colours and sizes, along with rigorous quality check after every step, thus making TD high. These supply and operational constraints reduce I_V.
- The products with no disassembly and minor value addition (i.e. Groups 5 and 6) are expected to require comparatively less TD and S, due to lesser demand placed on disassembly and reassembly. However, the patched products (Group 5) require higher TD due to the need to join manually multiple patches on the base denim garment. Compared to group 5 denims, group 6 products required lesser TD for patchworking due to several factors affecting average sewing time, such as choice of fabric rigidity, design elements and size of selected patches.

6. Analytical discussion

6.1. Prescribing fashion remanufacturing process scalability solutions

Systematic evaluation of the remanufactured product groups, process stages and their key sourcing and operational requirements embedded in the *RemCo* case study, revealed clear solutions to overcome the scalability challenges, as summed in Table 2.

Inadequate access to right quality input material, as also highlighted as a challenge in extant literature (e.g. Casper and Sundin, 2018; Priyono and Idris, 2018; Singh et al., 2019), is found in case of remanufacturing of products in group 3, which are "cut, added and put-together" following a strategic and creative mix-and-match process. We find solutions embedded in remanufacturing of other product groups at *RemCo*, by standardizing the use of disassembled material across different fully-disassembled products or by conducting redesign activities (e.g. patchworks) independent of the input material type in "minor-value added" products. Such standardization approach through component commonality is also indicated by Kurilova-Palisaitiene et al. (2018), though low task standardization and inability to level production often arises as a major problem in remanufacturing operations due to inherent unreliability in quality (Priyono and Idris, 2018).

Another key challenge evident across many fashion remanufacturing product groups (1, 2, 3 and 5) at *RemCo* is long process throughput time, as also reflected in previous studies (e.g. Golinska-Dawson et al., 2015; Han et al., 2017; Singh et al., 2019). Among solutions prescribed in remanufacturing literature (e.g. Kurilova-Palisaitiene et al., 2018), we find use of visual aids or tools, such as construction charts helpful for improving fashion remanufacturing process efficiency. Remanufacturing literature have mostly highlighted rule-of-thumb heuristics for decision-making at different stages (Gallo et al., 2012), and in fashion context this is largely based on the creativity of the designer (Dissanayake and Sinha, 2015; Han et al., 2017). Unlike upcycling fashion processes where most often design ideas are experimentally developed by directly reworking the disassembled fabric pieces/second hand clothes through techniques such as draping (Dissanayake and Sinha, 2015), at *RemCo* development of design concepts and ideas are not generated through experimentation with the available material. Instead product design development is conducted beforehand in order to develop standard sketches and patterns for "sewn from scratch" products (as show in Fig. 1), or to determine and set the cutting positions in case of "cut, add and put-together" products (as show in Fig. 2). This enhances the formalized approach in the disassembly process stage, and thus process efficiency.

Finally, in order to counter the general lack of knowledge and skillset in remanufacturing (Priyono and Idris, 2018; Singh et al., 2019), that is otherwise required to conduct highly labour-intensive fashion remanufacturing more efficiently (Dissanayake and Sinha, 2015), *RemCo* has formalized its approach by creating standard codifications of remanufacturing techniques. This has been helpful in routinizing the workforce to perform certain creative remanufacturing steps in a more repetitive way. For instance, while producing the "sewn from scratch" products where patterns are cut out of initially formed 'snakes', this can help in increasing the scalability of the process. Such codifications are crucial in reducing dependency on tacit remanufacturing skills (based on experience) and creative capacity of individual designers/operators, and to routinize practices at the production floor. Typically, it has become easier for the operators to work across different product groups as they do not need to undergo product-specific trainings, but instead learn generic industrial sewing and tailoring via a standard training program that varies between 1

Table 2
Remanufacturing scalability solutions.

Remanufacturing challenge categories	Process-level scalability challenges	Scalability solution observed/prescribed	Interdependence
Sourcing of input material	**Low I_v (for group 3)** *... as process demands aggregated over dis- and re-assembly stages are high to create high filtering/removal.*	In other product groups (in Table 1), de/low coupling between dis- and re-assembly places lesser aggregation of stringent requirements on what to source, e.g. forming "snakes" is independent of reassembly type and styles in groups 1 and 2. Also in no-minor (in groups 5 and 6), the value-added patchworks etc. are independent of input material type (passing quality checks).	Process (De) Coupling
Process throughput time demand	**High TD (for groups 1, 2, 3, 5)**... *as process variability is high resulting in low remanufacturing volume.*	Improving process-level efficiency by creating formalized rules for disassembly. For full disassembly both standard panels are developed (in groups 1 and 2), while for semi-disassembly cutting is done at set positions and places (in group 3).	Formalized activities
Skillset requirement	**High S (for group 1)** *... as skill requirements are high for complex remanufacturing products.*	In other product groups (in Table 1), workforce skills were improved by creating standard codifications of remanufacturing techniques in order to routinize activities, e.g. in fully disassembled + fully reassembled products by forming snakes in standard, repetitive manner. Low skill specificity across product groups to reduce challenges of dealing with high process variability.	Skill specificity

week and 2 months depending upon their initial skill level of the worker.

6.2. *Toward theorizing remanufacturing process scalability from interdependence perspective*

From the analysis above, we observe different forms of interdependences – explained by process *(de)coupling*, *formalization* of activities and skill *specificity* – in the tasks carried out within *RemCo*'s fashion remanufacturing processes – in particular during disassembly and reassembly. Bringing in process interdependence perspective, specifically derived from Thompson (1967), in terms of its nature, type of coordination, and characteristics (Crook and Combs, 2007), enable demystifying the process-level scalability challenges in fashion remanufacturing context.

Coupling, explains the nature of interdependence found in process/task dyads (Orton and Weick, 1990), thus providing clarification to the observed loosely-/de-coupled structure that exists between disassembly and reassembly in fashion remanufacturing. As evidenced from our findings, *decoupling* was observed in case of two remanufacturing process structures, first while producing standard "snakes" that was independent of the type and style of the remanufactured products, and second for redesign activities (e.g. patchworks) that was independent of the input material type. This reduced the interdependence between disassembly and reassembly, even though in general sequential interdependences are associated with higher inseparability and integrated functionalities (Thompson, 1967). This resulted in increasing the scope of standardizing the input material for different product groups, thus facilitating scalability. *Formalization*, as another crucial aspect of interdependence, explains to what extent are activities codifiable, thus practices can be transferred and routinized. Remanufacturing literature has mostly highlighted heuristic decision-making along different stages, based on the creative eye of the remanufacturer/designer. However, in our study, more formalized approach is noticed when developing procedures for disassembly and reassembly, compared to rule-of-thumb experimentation as normally conducted for generating design/development concepts in redesign or upcycling. Once the heuristic product design development method has been established, simple "rulebooks" are used to routinize the process, e.g. to determine the number of different panels to be used, and their combination, for constructing "snakes" for "sewn from scratch" products. Such formalization also generates low *specificity* of the remanufacturing skillset across different product groups, as revealed above, thus allowing more process repeatability.

7. Conclusion

In the paper, process-level challenges hindering scaling-up of fashion remanufacturing were studied. An SLR employed, revealed three categories of process-level challenges related to: sourcing of input material, process throughput time, and skillset requirement. These categories were further utilized for conducting the case study, focussed on exploring how these challenges are addressed and solved in order to achieve process-level scalability. Given a dearth in literature on remanufacturing process management in general, and particularly to explain scalability, the case study provides a theoretically grounded explanation to this problem. The findings show that low degree of *coupling*, high level of *formalization* of activities and low skill *specificity* while undertaking the remanufacturing processes (particularly disassembly and reassembly) can be ways to address process-level scalability challenges and devise solutions. Overall, our study pinpoints the necessity to build lower interdependence between disassembly and reassembly processes to improve scalability.

7.1. *Theoretical implications*

Specifically, this paper contributes by creating a better understanding of the how to tackle process-level challenges in remanufacturing by enhancing workflow, on the top of lean improvements as prescribed in Kurilova-Palisaitiene et al. (2018), thus result in improving scalability. In addition, established in the organizational theories of firms (e.g. Weick, 1976), the paper shows how the three inter-related concepts of *(de)coupling*, *formalization* and *specificity* explain the nature and characteristics of process/task interdependence that is sequential between disassembly and reassembly in fashion remanufacturing. This further illuminates the understanding of organizing *within* firm coordination between processes/tasks, for improving scale.

7.2. *Practical implications*

European Environment Agency (2019) clearly highlights that lack of scalability in circular operations as a major reason for the slow transition to European textile circular economy as implementation often stops at small-scale experiments and pilots due to not overcoming the scalability challenges. In light to this, by building on process-level scalability in fashion remanufacturing such circular business operations could be made viable economically, thus more mainstream. More specifically, systematic evaluation of product-process groupings and structures, along with key sourcing and operational conditions (as shown in Table 1) can be beneficial to evaluate process-level challenges for enterprises undertaking fashion remanufacturing within the broader context of circular economy. The suggested solutions in this paper, in terms of how to lower interdependence between disassembly and reassembly, can be useful as a guidance for devising solutions to overcome these challenges in fashion remanufacturing, and improve scalability.

7.3. Limitations and scope for future research

Scope for future research stems out of the limitations of this paper. Firstly, overall scalability potential of fashion remanufacturing depends not only on mitigating process-level challenges, as has been solely addressed in this paper, but is equally dependent on devising solutions at both system level (e.g. related to business model, product design, marketing) and industry level (e.g. customer preference, technological adoption) (Kurilova-Palisaitiene et al., 2018). Future research on scalability of fashion remanufacturing can create more holistic, three-level understanding of scalability solutions. In particular, from the system perspective that is largely influenced by business models, future research can concentrate on exploring scaling logics for remanufacturing, in terms of strategies, activities and resources. Secondly, our paper addresses scale entirely from an economic perspective, i.e. conjoined with the notion of volume and growth. Remanufacturing, within the circular economy context, extends beyond just producing economic value but also environmental, social and image values. Future work can concentrate on studying how these multi-dimensional value types can be generated and scale-up in fashion remanufacturing business models, beyond economic ones.

CRediT authorship contribution statement

Rudrajeet Pal: Conceptualization, Methodology, Writing, Supervision, Funding acquisition, Project administration. **Yasaman Samie:** Conceptualization, Investigation, Formal analysis. **Armaghan Chizayfard:** Conceptualization, Investigation, Formal analysis.

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.

Acknowledgements

The authors would like to thank the Region of West Sweden, Environmental Board and Jan Wallanders and Tom Hedelius Stiftelse (P18-0057) for financing the research for this paper.

Appendix 1. Detailed SLR findings

Remanufacturing process-level challenge categories *(based on* Kurilova-Palisaitiene et al., 2018)	Process-level remanufacturing challenges from SLR	Related evidences in fashion remanufacturing from SLR	Remanufacturing process-level challenge categories hindering scalability *(for further case study exploration)*	Prescribed solutions evident from SLR	Related evidences of solutions prescribed in fashion remanufacturing context
Core-related *Unpredictability in incoming core in terms of quantity, quality, variability, and timing (lack of proper acquisition and management)*	• Unreliability of returns and forecasts (i.e. in terms of variety, uncertainty, dynamics, size) (Casper and Sundin, 2018) • Supply shortage (Golinska-Dawson et al., 2015; Kalverkamp and Raabe, 2018) • Fluctuating demand and availability (Priyono and Idris, 2018) • Incoming quantity/recovery uncertainty, supply-demand mismatch (Lage and Godinho, 2016; Oh and Behdad, 2017; Zhang et al., 2018) • Stochastic returns (Li et al., 2015)	• Variability of the timing, quantity and quality of incoming materials (Dissanayake and Sinha, 2015; Keith and Silies, 2015; Han et al., 2017; Singh et al., 2019)	Sourcing of input material-related	• Internal coordination (e.g. vertical integration), Increasing component specificity and standardize operations (Kalverkamp and Raabe, 2018; Kurilova-Palisaitiene et al., 2018) • Diverse supply sources and networks (Golinska-Dawson et al., 2015; Kurilova-Palisaitiene et al., 2018)	• Building collaborative networks (Dissanayake and Sinha, 2015)
Operations-related *Unpredictable and long processing and waiting times*	• Random operation time (Li et al., 2019) • Random lead/throughput time (Golinska-Dawson et al., 2015) • High manual work (Seitz and Wells, 2006)	• Time-consuming processes (Singh et al., 2019) • Long lead time (Han et al., 2017) • Labour-intensive (Dissanayake and Sinha, 2015)	Process throughput time-related Skillset requirement-related	• Continuing qualification, Early engagement with NPD (Casper and Sundin, 2018) • Automated disassembly technology (Franke et al., 2006)	• Using modular manufacturing methods (Han et al., 2017) • Centralized role of designer-maker; Creative capacity and thinking (Dissanayake and

(*continued*)

Remanufacturing process-level challenge categories *(based on* Kurilova-Palisaitiene et al., 2018)	Process-level remanufacturing challenges from SLR	Related evidences in fashion remanufacturing from SLR	Remanufacturing process-level challenge categories hindering scalability *(for further case study exploration)*	Prescribed solutions evident from SLR	Related evidences of solutions prescribed in fashion remanufacturing context
					Sinha, 2015; Han et al., 2017) • Process technologies, e.g. pattern cutting software (Dissanayake and Sinha, 2015)
Operations-related *Unreliability in remanufacturing process sequence & capacity, remanufacturing scheduling & planning*	• Job shop scheduling complexity, random operation times, high variability in processing times and stochastic routings (Lage and Godinho, 2016; Zhang et al., 2018; Li et al., 2019) • Low reliability (Jiang et al., 2016) • Lack of knowledge and skill in monitoring product-process reliability (Lie et al., 2018; Priyono and Idris, 2018) • Inability to level production, low task standardization (Priyono and Idris, 2018) • Lack of capacity planning (Franke et al., 2006)	• Variability in processing lead time resulting in difficulty in capacity planning and scheduling (Dissanayake and Sinha, 2015) • Lack of required skillset (Dissanayake and Sinha, 2015)	Process throughput time-related Skillset requirement-related	• Recovery route selection and resource dispatching (Li et al., 2019) • Aggregate capacity planning & scheduling (Lage and Godinho, 2016) • Optimal line design, dynamic facility layout (Li et al., 2015; Kurilova-Palisaitiene et al., 2018; Kwak, 2018) • Step-by-step visual tools for creating a Knowledge support system, Standard instructions/checklists (Lie et al., 2018; Kurilova-Palisaitiene et al., 2018) • Technology-enabled data capturing/monitoring (Zhang et al., 2018)	• Using modular manufacturing methods (Han et al., 2017) • Centralized role of designer-maker; Creative capacity and thinking (Dissanayake and Sinha, 2015; Han et al., 2017) • Process technologies, e.g. pattern cutting software (Dissanayake and Sinha, 2015)
Operations-related *High level of inventory*	• High minimum inventory level (Seitz and Wells, 2006; Casper and Sundin, 2018)	Not explicitly mentioned as a challenge for fashion remanufacturing	X	• Optimize buffer allocation by maximizing throughput rate and minimizing work in progress (Su et al., 2017; Kurilova-Palisaitiene et al., 2018) • Better forecasting (Lage and Godinho, 2016)	Not explicitly mentioned for fashion remanufacturing
Product quality-related *Product reliability and safety issues*	• Unclear/uncontrollable quality (Li et al., 2015; Casper and Sundin, 2018) • Uncertain quality (Su et al., 2017) • Lack of knowledge and skill in monitoring quality (Lie et al., 2018) • Less standardized quality control/inspection (Priyono and Idris, 2018)	• Variability of the quality of incoming materials (Dissanayake and Sinha, 2015; Keith and Silies, 2015; Singh et al., 2019) • Lack of required skillset (Singh et al., 2019)	Sourcing of input material-related Skillset requirement-related	• Integrated quality evaluation (Jiang et al., 2016) • Standard operations, instructions and checklists (Kurilova-Palisaitiene et al., 2018) • Automated disassembly technology (Franke et al., 2006) • Employee cross-training (Kurilova-Palisaitiene et al., 2018)	• Process technologies, e.g. pattern cutting softwares (Dissanayake and Sinha, 2015) • Different making strategies and techniques, i.e. design solutions (Keith and Silies, 2015)
Cost-related *Cost fluctuations due to process uncertainty; Underdeveloped KPIs objectives*	• Low process reliability resulting in high remanufacturing cost (Jiang et al., 2016) • Lack of process organization resulting in low economies of scale (Golinska-Dawson et al., 2015)	• Design-led, time consuming production resulting in high price and lack of economies of scale (Han et al., 2017; Singh et al., 2019)	Process throughput time-related	• Integrated quality evaluation during remanufacturing to improve reliability at low cost (Jiang et al., 2016) • Automated disassembly technology (Franke et al., 2006)	• Well-planned production schedules (Han et al., 2017) • Flexibility and technique for design and pattern cutting allowing waste minimization (Keith and Silies, 2015; Han et al., 2017)
Upgradability-related *Lack of evaluation of customer's demand and requirement; Apply upgrade strategy linked to revenue generation*	• Product value depreciation due to technology obsolescence (Oh and Behdad, 2017) • Lack of disassembly technology (Priyono and Idris, 2018)	Technology/technique is a key enabler (Han et al., 2017; Singh et al., 2019), but lack of technology is not considered a challenge to upgrade, as the role of creative labour is crucial.	X	• Cost-benefit for inventory holding for remanufacturing vs. recycling, over time (Oh and Behdad, 2017)	Solutions are more market awareness and pricing related.

Appendix 2. Key question set for case study

1. What kind of products do you have and why? How are these produced?
2. How do you train the workers to make these products?
3. What criteria are important for choosing product development patterns?
4. What are the key operational challenges faced during the remanufacturing steps, such as those related to material input, product development and production, quality etc.?
5. Do you have any seasonal challenges, e.g. related to demand?
6. Do have any problem with sourcing the raw materials? Is it for all or for some product groups?
7. How do you deal with challenges, such as lack of volume, standard size ratio and color? Are these problems for all or some product groups?
8. How you put your workforce in different training sessions and how you put them in different production stages?
9. Which factors play significant role for gaining economies of scale in the remanufacturing process?

References

Aras, N., Verter, V., Boyaci, T., 2006. Coordination and priority decisions in hybrid manufacturing/remanufacturing systems. Prod. Oper. Manag. 15 (4), 528–543.
Casper, R., Sundin, E., 2018. Addressing today's challenges in automotive remanufacturing. J. Remanufacturing. 8 (3), 93–102.
Charter, M., Gray, C., 2008. Remanufacturing and product design. Int. J. Prod. Dev. 6 (3/4), 375–392.
Crook, T.R., Combs, J.G., 2007. Sources and consequences of bargaining power in supply chains. J. Oper. Manag. 25 (2), 546–555.
Dissanayake, G., Sinha, P., 2015. An examination of the product development process for fashion remanufacturing. Resour. Conserv. Recycl. 104, 94–102.
European Environment Agency, 2019. Textiles and the environment in a circular economy (Eionet Report - ETC/WMGE 2019/6). available at: https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-reports/textiles-and-the-environment-in-a-circular-economy. Accessed 20 June 2020.
Ferguson, M., 2009. Strategic and tactical aspects of closed-loop supply chains. Foundations and Trends® in technology. Inf. Oper. Manag. 3 (2), 101–200.
Flyvbjerg, B., 2006. Five misunderstandings about case-study research. Qual. Inq. 12 (2), 219–245.
Franke, C., Basdere, B., Ciupek, M., Seliger, S., 2006. Remanufacturing of mobile phones-capacity, program and facility adaptation planning. Omega 34 (6), 562–570.
Gallo, M., Romano, E., Santillo, L.C., 2012. A perspective on remanufacturing business: issues and opportunities. In: Bobek, V. (Ed.), International Trade from Economic and Policy Perspective. Intech. https://doi.org/10.5772/48103.
Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: notes on the Gioia methodology. Organ. Res. Methods 16 (1), 15–31.
Golinska-Dawson, P., Kosacka, M., Nowak, A., 2015. Automotive parts remanufacturing - experience of Polish small companies. Chiang Mai University J. Nat. Sci. 14 (4), 415–430.
Goodall, P., Rosamond, E., Harding, J., 2014. A review of the state of the art in tools and techniques used to evaluate remanufacturing feasibility. J. Clean. Prod. 81, 1–15.
Gwilt, A., Rissanen, T., 2011. Shaping Sustainable Fashion: Changing the Way We Make and Use Clothes. Earthscan, London.
Han, S.L.C., Chan, P.Y.L., Venkatraman, P., Apeagyei, P., Cassidy, T., Tyler, D.J., 2017. Standard vs. Upcycled fashion design and production. Fash. Pract. 9 (1), 69–94.
He, Y., 2015. Acquisition pricing and remanufacturing decisions in a closed-loop supply chain. Int. J. Prod. Econ. 163, 48–60.
Janigo, K.A., Wu, J., DeLong, M., 2017. Redesigning fashion: an analysis and categorization of women's clothing upcycling behavior, fash. In Pract. 9 (2), 254–279.
Jiang, Z., Zhou, T., Zhang, H., Wang, Y., Cao, H., Tian, G., 2016. Reliability and cost optimization for remanufacturing process planning. J. Clean. Prod. 135, 1602–1610.
Kalverkamp, M., Raabe, T., 2018. Automotive remanufacturing in the circular economy in europe: marketing system challenges. J. Macromarketing 38 (1), 112–130.
Keith, S., Silies, M., 2015. New life luxury: upcycled Scottish heritage textiles. Int. J. Retail Distrib. Manag. 43 (10–11), 1051–1064.
Kleber, R., Reimann, M., Souza, G.C., Zhang, W., 2018. On the robustness of the consumer homogeneity assumption with respect to the discount factor for remanufactured products. Eur. J. Oper. Res. 269 (3), 1027–1040.
Krystofik, M., Wagner, J., Gaustad, G., 2015. Leveraging intellectual property rights to encourage green product design and remanufacturing for sustainable waste management. Resour. Conserv. Recycl. 97, 44–54.
Kurilova-Palisaitiene, J., Sundin, E., Poksinska, B., 2018. Remanufacturing challenges and possible lean improvements. J. Clean. Prod. 172, 3225–3236.
Kwak, M., 2018. Optimal line design of new and remanufactured products: a model for maximum profit and market share with environmental consideration. Sustainability 10 (11). https://doi.org/10.3390/su10114283.
Lage Jr., M., Godinho Filho, M., 2016. Production planning and control for remanufacturing: exploring characteristics and difficulties with case studies. Prod. Plan. Control. 27 (3), 212–225.
Langley, A., 1999. Strategies for theorizing from process data. Acad. Manag. Rev. 24 (4), 691–710.
Langley, A., Abdallah, C., 2011. Templates and turns in qualitative studies of strategy and management. In: Bergh, D., Ketchen, D. (Eds.), Building Methodological Bridges. Res. Methodol. Strategy Manag. 6. Emerald, Bingley, pp. 201–235.
Li, L., Li, C., Ma, H., Tang, Y., 2015. An optimization method for the remanufacturing dynamic facility layout problem with uncertainties. Discrete Dyn. Nat. Soc. https://doi.org/10.1155/2015/685408 art. no. 685408.
Li, L., Li, C., Li, L., Tang, Y., Yang, Q., 2019. An integrated approach for remanufacturing job shop scheduling with routing alternatives. Math. Biosci. Eng. 16 (4), 2063–2085.
Lie, L.W., Aziz, N.A., Wahab, D.A., Rahman, M.N.A., Azhari, C.H., 2018. Enhancing remanufacturing efficiency in Malaysia through a knowledge support system: a case study of brake calipers. Int. J. Ind. Syst. Eng. 28 (4), 451–467.
Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. J. Clean. Prod. 115, 36–51.
Nasr, N., Thurston, M., 2006. Remanufacturing: A Key Enabler to Sustainable Product Systems. Rochester Institute of Technology, New York.
Niinimäki, K., Hassi, L., 2011. Emerging design strategies in sustainable production and consumption of textiles and clothing. J. Clean. Prod. 19 (16), 1876–1883.
Oh, Y., Behdad, S., 2017. Simultaneous reassembly and procurement planning in assemble-to-order remanufacturing systems. Int. J. Prod. Econ. 184, 168–178.
Orton, J.D., Weick, K.E., 1990. Loosely coupled systems: a reconceptualization. Acad. Manag. Rev. 15 (2), 203–223.
Pal, R., Gander, J., 2018. Modelling environmental value: an examination of sustainable business models within the fashion industry. J. Clean. Prod. 184, 251–263.
Priyono, A., Idris, F., 2018. Analysing the adoption of lean production in remanufacturing industry. J. Ind. Eng. Manag. 11 (4), 697–714.
Pulse of the Fashion Industry, 2017. Global fashion agenda & boston consulting group. available at: https://www.copenhagenfashionsummit.com/wp-content/uploads/2017/05/Pulse-of-the-Fashion-Industry_2017.pdf. Accessed 20 June 2017.
Seitz, M.A., Wells, P.E., 2006. Challenging the implementation of corporate sustainability: the case of automotive engine remanufacturing. Bus. Proc. Manag. J. 12 (6), 822–836.
Singh, J., Sung, K., Cooper, T., West, K., Mont, O., 2019. Challenges and opportunities for scaling up upcycling businesses – the case of textile and wood upcycling businesses in the UK. Resour. Conserv. Recycl. 150 art. no. 104439.
Su, C., Shi, Y., Dou, J., 2017. Multi-objective optimization of buffer allocation for remanufacturing system based on TS-NSGAII hybrid algorithm. J. Clean. Prod. 166, 756–770.
Swain, J., Spire, Z., 2020. The role of informal conversations in generating data, and the ethical and methodological issues they raise. Forum Qual. Soc. Res. 21 (1). https://www.qualitative-research.net/index.php/fqs/article/view/3344/4511. Accessed 16 September 2020.
Thompson, J.D., 1967. Organizations in Action: Social Science Bases of Administrative Theory. McGraw Hill, New York.
Vogtlander, J., Scheepens, A., Bocken, N., Peck, D., 2017. Combined analyses of costs, market value and eco-costs in circular business models: eco-efficient value creation in remanufacturing. J. Remanufacturing 7 (1), 1–17.
Wacker, J.G., 1998. A definition of theory: research guidelines for different theory-building research methods in operations management. J. Oper. Manag. 16 (4), 361–385.
Weick, K.E., 1976. Educational organizations as loosely coupled systems. Adm. Sci. Q. 21, 1–19.
Wen-hui, X., Dian-yan, J., Yu-ying, H., 2011. The remanufacturing reverse logistics management based on Closed-loop supply chain management processes. Procedia Environ. Sci. 11, 351–354.
Woolridge, A., Ward, G., Phillips, P., Collins, M., Gandy, S., 2006. Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: an UK energy saving perspective. Resour. Conserv. Recycl. 46 (1), 94–103.
Young, C., Jirousek, C., Ashdown, S., 2004. Undesigned: a study in sustainable design of apparel using post-consumer recycled clothing. Cloth. Text. Res. J. 22 (1–2), 61–68.
Zhang, Y., Liu, S., Liu, Y., Yang, H., Li, M., Huisingh, D., Wang, L., 2018. The 'Internet of Things' enabled real-time scheduling for remanufacturing of automobile engines. J. Clean. Prod. 185, 562–575.