RESEARCH

Designing for circular fashion: integrating upcycling into conventional garment manufacturing processes

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Abstract

This paper summarises the results of a more than 5-year practice-led study on the use of upcycling design and production methods in garment mass production. The efficiency of upcycling design approach is described by analysing the generation and potential use of various types of fabric leftovers from garment manufacturing. The results of this research show that depending on the size of the factory the fabric leftovers and textile waste generated in garment production ranges from 25–40% of the total fabric used. Experiments show that 50% of that material can be upcycled into new garments and for some types of leftover—mainly spreading loss and excess fabric—it can even be up to 80%. Implementing upcycling on the industrial level requires transparency to understand the waste created in garment production and create designs that suite the production system. It is important to consider that the upcycling design process differs from regular design—a garment is designed based on the parameters of the waste materials.

Keywords: Circular fashion, Garment manufacturing, Textile waste and leftovers, Upcycling design

Introduction

The fashion and textile industry is one of the world's most polluting industries, mainly because its volume of production dwarfs most other industries. Textiles production requires a lot of land for crops and uses a lot of water, energy, chemicals and other resources leaving often untreated pollution behind and has a highly negative environmental, economic and social footprint (Fletcher, 2008; GFA & BCG, 2017; Hiller Connell & Kozar, 2017; Leal et al., 2019; Remy et al., 2016). Today's conventional fashion and garment industry is linear by nature and in addition to the impact that raw material extraction for newly produced fibre production has, textile waste has become a major problem in the sector (Ellen MacArthur, 2013, 2017).

The amount of waste created is truly significant, as the European Union (EU) textile industry alone generates around 16 million tonnes of textile waste annually (European Commission, 2017). Much of this waste today still ends up in landfills or is incinerated. This represents a loss from a production effort which uses millions of tonnes of water

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and kilowatts of energy, and countless hours of human labour that could be salvaged (Leal et al., 2019).

While most debates and circular fashion approaches focus on the problem of used garments—so-called post-consumer waste (Fischer & Pascucci, 2017; Singh & Ordoñez, 2016), less attention is paid to the textile waste and leftovers from manufacturing garments (pre-consumer waste). Yet the environmental impact of garment production in the whole garment life cycle can be from 29 to 72% depending on the type of clothing (Steinberger et al., 2009).

Over the past 30 years, most garment production has shifted to developing countries, mainly in Asia, in search of cheaper labour. Global clothing supply chains are now complex involving several actors on many levels and regions making it difficult to have full oversight on them. This results in the waste generated in the production being less visible and less recognised by brands, designers as well as consumers (Govindan & Hasanagic, 2018).

However, awareness that the textile waste generated during garment production is a problem is starting to increase mainly of economic reasons. Fabric can make up to 80% of the total production cost of a garment, which has made manufacturers to seek ways to decrease the creation of waste as much as possible (Nayak et al., 2008). Recycling technologies for textile production waste and leftovers are also being sought and developed (Leal et al., 2019; Lewis et al., 2016). The problem of textile production waste is still mainly left for manufacturers to solve. The unofficial waste management system in those manufacturing countries is unpredictable and the availability of different recycling options is very limited. Therefore, most of the leftover material from garment manufacturing ends up dumped or burned.

The aim of this study was to analyse the amount and types of textile waste and fabric leftovers generated in the garment manufacturing process that are most suitable for what is called industrial upcycling so as to redirect the leftover material back into the production of new garments. In addition, a summary of innovative design methods and examples of garment designs for upcycling textile waste is presented. These methods and examples were developed and tested during this research, which also formed the foundation for the development of a new circular design business model, UPMADE. It is the first of its kind circular garment design and production approach based on the principles of upcycling and has proven to be applicable in mass production in several garment manufacturing factories in Asian countries (SEI, 2019).

Literature review
Circular fashion
In recent years, the circular economy, as the opposite approach to the current linear economy, has been one of the most important areas of environmental policy affecting the fashion and textile industry among others (Ellen MacArthur, 2017). Circularity relates to the intention to minimize waste and keep textile products within a cycle of use throughout the process of design, manufacture and consumption until they are returned safely to the biosphere once they have no further use (Brismar, 2017; Niinimäki, 2017). Today, fashion and textile companies are searching for new circular solutions to reduce their environmental impact. Over the past decade, a variety of new technological

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approaches to design and business models have been developed to rethink the various stages of product development and textile production with a focus on circularity, incorporating an emphasis on ecologically sustainable materials, which can easily be reused and or recycled back into the production cycle (Gazzola et al., 2020; Goldsworthy et al., 2018; Niinimäki, 2017). With an increasing concern amongst consumers towards the social and environmental impact of their purchases, businesses are beginning to understand the financial benefits of highlighting a circular approach. Even though the circular economy and problem of waste is gaining more attention, it can be said that fashion and textile industry still lags behind other sectors (Niinimäki, 2013, 2017).

Measuring and creating visibility for textile waste can unlock major opportunities for material circulation using fabric leftovers from garment production and associated economic benefits (Bocken et al., 2017; De los Rios & Charnley, 2017). Providing innovative circular design methods for fabric leftovers and textile waste can significantly reduce the environmental impact of the fashion and textile industry and lead to a virtuous circle in which financial savings also lead to a positive environmental impact and lead to a win–win partnership (Lieder & Rashid, 2016).

Upcycling as a new design principle for circular fashion

More and more fashion designers are turning to the concept of upcycling. Over the last decade the term 'upcycling' has been coined and worked into the discourse of sustainability efforts. It first appeared in William McDonough's book, Cradle to Cradle (McDonough & Braungart, 2002). The term has a number of definitions and practices and it has mainly been used in connection with fashion and textiles. Upcycling can be defined as a recycling approach where "waste"—textile leftovers that would usually end up in landfill or incineration—is used to create products with a higher retail value than traditional recycled products (Aus, 2011; Cassidy & Sara, 2012; Han et al., 2015, 2017; Teli et al., 2015). As such, upcycling can be described as the opposite of downcycling, which downgrades the value of the material and discards the work and value invested in it.

Traditionally textile waste recycling refers to the reprocessing of textile waste (mechanically or chemically) for use in both new textile products and non-textile products (Sandin & Peters, 2018). Upcycling is generally understood as a design-based circular fashion approach, where pre- or post-consumer textile waste material is repurposed to create new garments (Aus, 2011).

Upcycling is a growing trend among fashion designers, helping to save resources and keep tonnes of textile waste out of the waste stream. More and more brands and fashion houses are waking up to the method and applying it as they seek solutions to the industry's environmental impact and to offer socially and environmentally conscious choices to their customers. Some of the best-known upcycling designers who use pre-consumer textile waste and leftovers are for example Reet Aus from Estonia, British designer Christopher Raeburn and Zero Waste Daniel from New York (Giordano, 2019).

Until recently, however, upcycling has mostly been used on a small scale, sold as unique pieces or added elements in some collections, and not on an industrial scale (Moorhouse & Moorhouse, 2017).

Implementing upcycling on the industrial level requires transparency to understand the waste created in mass production and create designs that suite the production

system and make it less wasteful. It is important to consider that the upcycling design process differs from regular design—a garment is designed based on the parameters of the waste materials (Aus, 2011; Han et al., 2015, 2017).

One of the main obstacles to the use (and upcycling) of leftover material in the fashion and textile industry is the lack of data about the textile waste generated in the garment manufacturing. The volume of textile leftovers is systematically underreported and thus underestimated by the industry (Runnel et al. 2017a, b). Leftover generation and fabric loss from garment production (mainly from the cutting and sewing process) is relatively well known and the manufacturers are making considerable efforts to optimise their processes and avoid or minimise waste (Nayak et al., 2008; Saeidi & Wimberley, 2017; Townsend & Mills, 2013). However, very little research has been done to analyse and estimate the amount of fabric waste that is related to other problems with fabric quality as well as manufacturing and resource planning (Runnel et al., 2017a, b).

Although upcycling uses traditional fashion design techniques (e.g. sketches, mood-boards and sample making), the designs are determined by the available surplus stock of fabric leftovers that can vary in size and shape. Therefore, the starting point is always a detailed overview of the waste streams and identifying the type and quantity of available materials (Aus, 2011). This requires flexibility from the designer, comprehension of the production processes and a sense of systems thinking. It also requires close cooperation and information exchange between the brand or, the designer and the manufacturer. However, compared to other textile waste recycling solutions the garments designed from textile waste and leftovers can be manufactured in the existing garment manufacturing sites, utilising existing infrastructure without the need to invest into additional technologies (SEI, 2019). This offers a great opportunity for an efficient upcycling of textile waste from manufacturing processes.
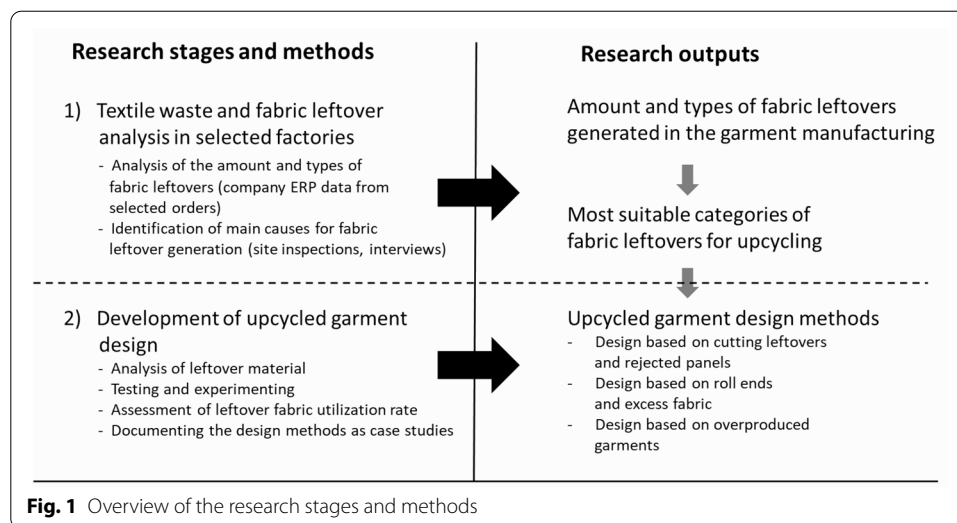
Methods

This study is a practice-led (Candy, 2006; Gam & Banning, 2011) research project aimed at gaining a new understanding of the practice of upcycled fashion design and its implementation in the mass production of garments. The study was based on five years of comprehensive field research in four factories in Bangladesh, India and Estonia, where the upcycling design approaches were developed together with an accompanying business model to integrate and implement them.

This practice-led research was completed in two main stages, as illustrated in Fig. 1

Textile and fabric leftover analysis in selected garment manufacturing companies

The results of the detailed textile waste and fabric leftover analysis were formulated based on investigations of two garment manufacturers. The first in Bangladesh, employs around 40,000 workers and produces approximately 240 million garments a year for a few dozen brands. It represents a classical large-scale textile manufacturer and the particularities of production processes of that scale. The other company is in India and employs around 400 workers and represents a typical small garment manufacturer with smaller output and fewer clients. They both service mainly European and Northern American fashion brands.

Research stages and methods

1) Textile waste and fabric leftover analysis in selected factories
   - Analysis of the amount and types of fabric leftovers (company ERP data from selected orders)
   - Identification of main causes for fabric leftover generation (site inspections, interviews)

2) Development of upcycled garment design
   - Analysis of leftover material
   - Testing and experimenting
   - Assessment of leftover fabric utilization rate
   - Documenting the design methods as case studies

Research outputs

Amount and types of fabric leftovers generated in the garment manufacturing

Most suitable categories of fabric leftovers for upcycling

Upcycled garment design methods
- Design based on cutting leftovers and rejected panels
- Design based on roll ends and excess fabric
- Design based on overproduced garments

Fig. 1 Overview of the research stages and methods

The textile waste and leftover analyses were carried out via repeated site inspections, interviews with key staff and screenings of Enterprise Resource Planning (ERP) data extracts as well as material and waste inventory data for both studied companies. The main categories of textile waste and fabric leftovers presented in this research are derived from a general classification used in the textile industry (Nayak et al., 2008; Ng et al., 1999; Saeidi & Wimberley, 2017; Townsend & Mills, 2013). The types and causes of manufacturing related fabric leftovers and loss generation were also studied in both companies during the waste analysis.

The detailed analysis of fabric leftover and waste generation was based on company ERP data from selected orders that contained vital information, such as amount of fabric used, average marker efficiency, rejected and excess fabric, excess garments, that allowed us to calculate the amount of fabric leftover generated with each order. The generation of different types of fabric leftovers was calculated according to the most common garment categories—T-shirts (jersey), trousers (denim), men's shirts (woven) and dresses (woven). In each of the two factories, 10 random orders for all four garment categories were analysed. The average order size in the large factory was around 32,000 products and 1500 products in the smaller factory. Based on the analysis of these orders, it was possible to calculate the weighted averages of the share of fabric waste in the main studied categories of leftovers.

Development of upcycled garment design methods
From that waste analysis, the categories of leftovers with the greatest potential for upcycling were identified and then matched with developed design approaches. The applicability and efficiency of upcycling garment designs were tested on each selected fabric leftover category. During the testing, the suitability of the fabric leftovers for upcycling design and mass production was assessed in terms of total available material, as well as size, shape and other parameters. The selected leftover categories with higher potential for upcycling in mass production were used for a series of tests to further develop the suitable upcycling design methods that were documented as case studies.

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In those tests the total use potential of that particular leftover category for making new upcycled garments was assessed. Specific types of textile leftovers from the selected orders (5 orders from each tested leftover category) were separated and used for producing new upcycled garments following a developed design method. The total quantity of the particular material that was sent for upcycling was measured as well as the amount of fabric utilisation in the actual upcycling process. The amount of leftover fabric used in upcycling was determined by measuring the surface area (e.g. width and length of roll ends/excess fabric or pattern layout of cut pieces) or weight (rejected panels and overproduced garments). The results of the measuring allowed us to calculate the average percentage of the leftover fabric used to indicate how much of specific leftovers it is possible to use for upcycling new garments.

Results and discussion

Textile waste and leftover generation in the garment manufacturing

Implementing an upcycling-based garment design and production process requires a good understanding of textile waste and leftover generation in the garment manufacturing process. However, usually this data is not available to designers, and therefore it is difficult to introduce upcycling approaches on an industrial scale. Here we describe the main causes of textile waste with the results of our research on their volumes in the garment industry.

Main causes of textile waste and leftover generation

Textile waste is one by-product of garment manufacturing, and usually it is deemed unusable for its original purpose. Fabric waste and leftovers are generated at various stages of the garment production process and their volumes and causes can differ significantly (Runnel et al. 2017a, 2017b).

In general, there are three main reasons for fabric leftover generation and fabric loss in the garment manufacturing:

- Leftovers due to the technical particularities of production processes (e.g. cutting waste, roll ends, sewing damage and defects)
- Problems with quality of fabric (e.g. defective, damaged or unsuitable fabric)
- Problems related to manufacturing and resource planning (e.g. excess fabric, order faults or cancellations, over production)

Leftovers from garment production process

Textile waste and leftovers generated during garment manufacturing can be categorised based on technical particularities of the production processes as follows.

Sampling fabric leftovers

Textile leftovers are already generated in the product development stage. During this stage several samples are usually made on which the final production design is decided and the production processes are tested and planned. Typically, part-finished or finished garment samples and textile swatches are considered as factory surplus textile leftovers.

However, fabric leftovers and not used samples that are produced during the sampling stage form a very small part of the total generation of textile/garment leftovers.

Fabric leftovers and losses from cutting

Cutting is the major stage among the various processes of garment production where most of the fabric waste/leftovers is generated. The amount of fabric loss in the cutting process depends on many aspects. During the cutting process two main types of fabric losses occur—marking loss and spreading loss (Nayak et al., 2008).

Marking loss arises due to the gap and the non-usable areas between the pattern pieces of a marker. Marker efficiency indicates the amount of marking loss. Marker efficiency is commonly affected by fabric characteristics, shapes of pattern pieces, fabric utilisation standards and marker quality. The higher the marker efficiency the higher the fabric usage and smaller the wastage. The area between pattern pieces, which is not used for garment parts, is usually called cut pieces.

The various fabric losses outside the marker can be broadly classified into the following groups (Nayak et al., 2008):

- Edge loss—occurs due to variable fabric widths. The width of the marker is usually a few centimetres less than the edge-to-edge width of the fabric. This loss on the sides of fabric roll is called edge loss.
- End loss—is an allowance left at both ends of a fabric ply in a spread to ease cutting. The end loss should be as small as possible (standard end loss is 2–4 cm, but it could be more depending on the quality of the cutting process). The greater the fabric length the less waste.
- End bits and roll ends—during the spreading process, the variation in length of fabric between the fabric rolls as well as roll allocation could result in the generation of significant amount of remnant fabric loss or roll ends in different lengths.

In addition to the abovementioned leftover types, rejected panels could be brought up as a specific type of fabric leftover from the cutting process. Rejected panels are segregated after cutting when defects on the fabric are spotted or mistakes were made during cutting. The most common reason for rejection is defects in the fabric itself and different brands have different quality standards for the number of defects per square metre.

Fabric leftovers and losses from sewing

Fabric leftovers generated during the sewing stage are usually related to sewing damages and defects in the fabric. While some of the defects can be corrected, oil stains from sewing machines, uneven panels or other permanent defects result in rejecting the whole garment. That means the majority of the textile waste involves partial or complete garments that have been separated during quality control. The frequency and therefore the total amount is directly in correlation with the quality of the sewing process of the manufacturer depending on the suitability of the fabric and other materials, the competence of the sewers and the quality of the machinery.

Leftovers related to fabric quality

Whether the fabric is produced in-house (vertically integrated production) or ordered in, it can happen that the fabric has unrepairable faults in it. The following reasons cause the largest amounts of leftover fabric:

- Unsuitable fabric—the main reason a fabric already sourced is not used in the production is when it deviates from the initial order. Problems with the specifics of the colour are the most common but also feel and other qualities. Although there is an industry-wide system for colour standards to make sure of the specific colour type, in reality variations occur.
- Defective fabric—typical defects during the manufacturing process include back fabric seam impression, birds eye, bowing, broken colour pattern, colour out, colour smears, crease mark, mistakes in drop stitching, dye streak in printing, holes, jerk in, knots, mixed yarn, mottled, needle line, open reed, pin holes, press off and others.
- Damaged fabric—damage can occur during storage, treatment or transportation if the proper conditions for humidity, ventilation etc. have not been met. That is also why various chemicals are often applied to deter the growth of fungi.

Leftovers related to manufacturing and resource planning

The garment industry has become a very consumer-driven industry, and this affects the relationship between brands and manufacturers. Manufacturing companies have to compete globally to respond to client demands. They cannot afford to lose time in the production process because this can lead to penalty fees when products aren't delivered as promised. Buyers can quickly find other companies to replace manufacturers who cannot deliver. As styles are now changing rapidly the brands demand increasingly shorter lead times between ordering and delivery and many of them make increasingly smaller orders that are diffused amongst a number of manufacturers. To keep up with changing trends, manufacturers are pressured to plan and control their manufacturing processes accordingly. This results in manufacturers having to pre-plan and store sufficient supply of fabrics and plan for over-production to minimise delivery risks.

The main reasons a significant volume of fabric can be left unused include the following:

- Order faults or cancellation—sometimes the client cancels the order for internal reasons. Although, usually the material cost is fully covered by the client, some of the material can already be produced and ready but will not be used.
- Excess fabric—the minimum order quantity (MOQ) for fabric orders can be bigger than a smaller manufacturer will use to complete an order.
- Delays—these can occur when ordering or manufacturing the fabric. Contracts are strict and being pushed back even a few days can result in cancellation of the order.
- Over-production—the manufacturer has to deliver the products to the customer on an agreed date. The lead time can be as short as 30 days in vertically integrated

plants to cater for fast fashion, although it is usually 60 days. An average lead time is 30 days for making fabric and 45 days for producing garments. To avoid under delivering to the client, the risk of possible production errors from all stages are accounted for by planning an extra 3–5% of end produce. This results in over production of ready-made and ready to ship garments. If no mistakes are made during the manufacturing, then the excess production—even though it can be perfect in quality—is usually written off as waste. Sometimes the branding labels are removed from the ready-made garments and sold off to the local market.

Quantity of fabric leftovers from garment manufacturing

The results of the detailed analysis of fabric leftover and waste generation in two typical garment manufacturers—one large and one small—are presented in Table 1.

The results of the analysis show that there is significantly less fabric loss generated in the large manufacturing company compared to the smaller factory—the total share of leftovers was 24.7% and 39.2% respectively. The biggest difference is in the generation of cutting waste, where the share in the large factory is half that of the smaller factory in all forms—cut pieces from marking loss as well as end-pits and roll ends from spreading loss. The smaller proportion of waste in the large factory can be reasonably explained that they generally operate at a higher level of efficiency, larger orders allow them to better minimise cut waste from routines and fewer alterations. Furthermore, quality control works more diligently in larger factories. Smaller manufacturers have more fabric leftovers because their orders are smaller and the minimum purchase quantity is sometimes bigger than the order, which results in excess fabric.

Using the upcycling method in fashion design

The following section displays examples of selected upcycling design methods that were developed as a result of the leftover analysis and product development. Those designs have been successfully manufactured on actual mass production lines (smaller quantities have also been produced in more flexible facilities to create samples). The design methods are presented here according to the most suitable types of fabric leftovers for upcycling determined within this research:

- Design based on cutting leftovers (small cut pieces, end-pits and short roll ends 30 cm to 3 m) and rejected panels

Table 1 Average share of fabric leftovers in garment manufacturing

Type of fabric leftover	Large manufacturer	Small manufacturer
Cutting leftovers (marking loss)	12.0%	21.0%
End-pits and roll ends (spreading loss)	2.5%	4.2%
Rejected fabric and garments (quality issues)	4.2%	5.2%
Excess fabric	2.5%	3.7%
Over production	3.5%	5.1%
Total leftovers	24.7%	39.2%

- Design based on longer roll ends (3–49 m) and excess fabric
- Design based on overproduced garments

Design based on cutting leftovers

Cutting waste is the most abundant form of fabric leftover in the production process. Due to the small size and various shapes of cut waste its use in designing and producing upcycled garments is the most challenging. To effectively use such material, it is necessary to integrate the upcycling design into the garment production process.

The most difficult pieces to use in upcycling designs are the smaller cuts, which are in essence non-usable areas between the pattern pieces of the marker (so-called marking loss). Their amount and size varies from order to order due to the garment's design elements and order volume. To get the best use of the material, the panels for an upcycled garment have to be planned into the production and fit the empty spots on the original pattern. Gathering the cut pieces and later cutting them separately is too labour intensive, making it economically and technically unfeasible. Furthermore, cutting everything in one go with the original order is much easier and cheaper as it requires less handling and allows access to the main production lines. Interfering with the original production, however, requires good cooperation with the manufacturer and the brand's design team, as well as reacting fast when the original order is prepared for production. This means there are two main approaches to using cut leftovers.

The first approach is to design the upcycling product in parallel with the original primary product and its production planning. The pattern is prepared in the factory just before cutting. The details of the pieces for the upcycled garment must be ready by then to be placed into the original marker. The most efficient approach is when the client who orders the initial garment plans their side product into the pattern themselves. The amendments must be swift because the initial order cannot wait for the secondary designs. To be able to upcycle in such a way, an analysis of many patterns over time is required to develop products whose details are suitable to place into the gaps. The details (or some of them) of the design of the upcycled product are integrated into the empty areas in the original pattern and will be cut simultaneously on the cutting table. This makes it possible to maximise pattern efficiency and the use of potential cut waste pieces for the upcycled garment. Those added details will be separated during cutting and the new upcycled garment can be produced in parallel to the original one.

The second approach is to define standard details that can be added to the markers continuously whenever the empty areas between patterns have enough space to fit them. For example, certain triangles fit well between men's button up shirt patterns to combine into a new garment. At the cutting table those pieces are cut with the rest but separately collected to be later used in the production of certain types of upcycling products.

Cutting waste forms majority of textile waste produced throughout the production of garments, therefore in order to achieve maximum circularity, it is recommended to send cutting leftovers unsuitable to upcycling with the rest of the textile waste to mechanical recycling.

Example 1. Dress made from cutting pieces

One of the most efficient ways to minimise cutting leftovers is to design a product made from similar smaller pieces. That makes it possible to add those details into a marker that is already set up and the product will be cut at the same time. The details will be collected separately from the cutting table and sent for sewing. This method gives the opportunity to save up to 60% of the cutting leftovers, depending on the size of the detail added to marker. The example in Fig. 2 resulted in a 50% reduction in waste material.

It is somewhat easier to use the fabric leftovers generated outside the marker during the spreading process—shorter end-pits and roll ends, usually up to 3 m in length. The variability of the length of the pieces does not allow many layers of material to be cut together. Therefore, the most complicated and expensive step in the process is cutting. It has proven reasonable to proceed according to the shortest length of roll ends that in our experience has been 30 cm. This length dictates the size of a panel in a product that allows to use the most fabric. Such panels can be combined into one product that may therefore have several cuts in them.

The most efficient way to use the end-pits and shorter roll ends is to develop special garment designs as standard products that can be continuously made from separately collected fabric leftovers that come from nearly all orders (see Example 2 and 3, Figs. 3 and 4). This requires a clear procedure at the manufacturing site, for which

Fig. 2 Dress made from cutting leftovers (Design: Reet Aus, 2014. Photo: Gabriela Urm, reused with permission)

Fig. 3 Upcycled T-shirt designed from end-pits and short roll ends (Design: Reet Aus, 2019. Photo: Krõõt Tarkmeel, reused with permission)

Fig. 4 Upcycled dress designed from end-pits and roll ends (Design: Reet Aus, 2019. Photo: Krõõt Tarkmeel, reused with permission)

leftovers in terms of size, fabric type and other parameters must be separated at the cutting phase for later upcycling.

Example 2. Upcycled T-shirt

The size of the details of the T-shirt can depend on the size of the available waste pieces. In this example, short roll ends were used. This design has been in production for five years, the amounts and colour variations depend on the fabric available (see Fig. 3).

Example 3. Upcycled dress

This dress is another example of a design based on cutting waste—end-pits and short roll ends. The size of the details is driven by the size of the abovementioned waste pieces—here 30 cm long pieces were used. This particular model has been in production for two years in three different colour and fabric combinations.

The generated leftovers—end-pits and short roll ends—can be upcycled up to 80% in both examples. The design of example 3 allows even higher efficiency in using the leftover fabric because the square shape of the pattern makes it possible to use the "zero waste" approach.

It is also possible to use rejected panels in the aforementioned designs. The challenge here is gathering and preserving the material. Cutting is especially challenging, as they are usually smaller than end-pits and shorter roll ends, the amounts are unpredictable and there can be defects in the fabric. Therefore, it is a suitable material to be used in small quantities, garment details, or other non-garment design products. The production from rejected panels is expensive and requires high flexibility.

Design based on long roll ends and excess fabric

The longer roll ends (usually 3–49 m) are the most abundant type of textile waste, and due to their size, it is the most suitable material for making large quantities of upcycled garments. To ensure greater efficiency, roll ends longer than 3 m are instructed to be separated from the smaller ones at the cutting table, put back on a roll and stored separately or sent directly for upcycled garment production. The upcycled design is free of constraints when using larger roll ends, as the size does not determine the cuts. The easiest way to cut the larger roll ends is by creating a 3 m marker and the fabric can be laid out in 3 m layers on top of itself.

Example 4. Upcycled dress

This dress is designed to continue the overall style of the collection that has decorative cuts. This model has been in production for three years and it has been produced in five different fabric combinations. This method made it possible to upcycle 80% of such leftovers (Fig. 5).

Although producers try hard to avoid and reduce the amount of excess fabric it can still happen in significant volumes. The most reasonable solution is to use this excess in the production of other garments. In general, producers try to use such fabric in other orders or try to sell it to other smaller producers to be used in their production. Such fabric leftovers can also be used for making upcycled products, especially if they come in smaller volumes and in a variety of styles that are difficult to find a use for otherwise.

Example 5. Upcycled jeans

These jeans are produced from excess fabric that came from a cancelled order (see Fig. 6). Around 600 m has been stored separately for upcycling and the same model is being produced several times a year, 200 units at a time. Using the same fabric ensures consistent quality and can be used to make samples for new upcycled products. Furthermore, in this case up to 80% of the original leftover fabric was upcycled to produce new products.

Fig. 5 Upcycled dress designed from large roll ends (Design: Reet Aus. Photo: Krõõt Tarkmees)

Fig. 6 Upcycled jeans designed from excess fabric (Design: Reet Aus, 2019. Photo: Krõõt Tarkmeel, reused with permission)

Design based on overproduced garments

The best way to avoid this waste altogether is if brands had more flexibility with their orders. As they are generally good quality garments made according to the specifica- tions of the client, the best solution would be to sell them to the client. However, as this is most often not the practice, it is possible to use the material and upcycle it into new products with a different design. This is a complicated and costly process, as the products will have to be dismantled either partially or fully, create a clever and suitable design, recut the panels and resew them back into a new garment. A production like this is more suitable for a smaller manufacturer or a studio; it is not viable in mass produc- tion. However, it would be possible on the sampling lines of a large manufacturer where the production conditions are different and they have greater flexibility.

Example 6. Song Festival upcycled T-shirt

The factory had cancelled an order of 70,000 polo shirts. Those cancelled products were turned into 23,000 new T-shirts produced for the Estonian Song Festival. Because the cutting of the original products had to be done by hand it was a relatively complicated and time consuming process (Fig. 7).

Conclusions

Years of practical research in different garment manufacturing units has proven that industrial upcycling is a feasible and viable solution to pre-consumer textile waste. As shown in this research there are different volumes of fabric leftovers generated for differ- ent reasons that can be used for the manufacture of new garments using the upcycling design methods. Based on the results of this research, it can be said that depending on the size of the factory the textile waste and fabric leftovers generated in the garment manufacturing process ranges from 25 to 40% of the total fabric used. The results of test- ing of different upcycling design methods and leftover types show that 50% of that mate- rial can be upcycled into new garments and for some types of leftover—mainly spreading loss and excess fabric—it can even be up to 80%.

However, for the successful implementation of upcycling design and production sys- tem some requirements have to be fulfilled. Most importantly, the application of the upcycling model requires the initiative from the fashion brands who hold the power to

Fig. 7 T-shirt designed from overproduced garments (Design: Reet Aus 2013. Photo: Kerli Sosi, reused with permission)

order upcycled garments and therefore to reduce the textile waste and leftovers generation from making their products. The upcycling model also requires a higher level of trust between the brand and the manufacturer. On the other hand, the mutual interest of maximising the use of leftovers leads towards greater openness, exchange of information and long term cooperation that is a win–win solution to all involved. The manufacturers can form a long-term partnership with the brand it produces garments for and the brand, in turn, can get more out of their fabric if the manufacturer will also produce an upcycled collection from the fabric waste.

To be able to implement upcycling design methods the designers need to understand the types of leftovers generated and the reasons why this happens. Fabric leftovers and waste are generated because of technical aspects of the production processes, manufacturing and resource planning and quality issues. Cooperation between brands/designers and the manufacturer is crucial to understand the particularities of the material and to be able to design for it. For the efficiency of upcycling it is necessary to integrate the upcycling design into the garment production process, especially when working with cut leftovers.

The results of this research show that upcycling is a good opportunity to find the highest value for textile waste with relatively low cost by leveraging the existing capabilities and capacity of textile manufacturers. Upcycling pre-consumer waste makes it possible to work with homogenous and predictable material streams to manufacture the same upcycled garment designs in large quantities. Large amount of textile waste and leftovers can be redirected back into the production and upcycled into new garments in-house while greatly increasing the overall circularity of the sector.

Authors' contributions
RA and HM originated the research idea. HM developed the first draft of the manuscript, and all authors contributed to further writing, editing and review. MV helped with interpretation of study results. RA developed and tested the upcycling design methods. MV, RU, MK and SK with the guidance of HM conducted the textile waste and fabric leftover analysis. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets generated and analysed during the current study are available from the corresponding author on reasonable request. The detailed data that supports the waste generation calculation (sample orders of two manufacturing companies) is not publicly available due to commercial restrictions.

Declarations

Competing interests
The authors declare that they have no competing interests.

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