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Implementing circular economy principles in the apparel production process: Reusing pre-consumer waste for sustainability of environment and economy

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ABSTRACT

Environmentalists, the government, and the factory have always been more concerned with the inevitable pre-consumer waste produced by the apparel sector. The sustainable management of this enormous waste has received substantial attention from researchers. This study aims to experiment with a fresh approach to circular fashion, applying the circular economy principle of 'reusing' to manage the pre-consumer waste sustainably generated in the cutting section of the apparel industry. A specific style (boy's t-shirts) has been assessed to trace, gather, classify and quantify the reusable cutting waste produced in a factory located in Dhaka, Bangladesh, to introduce circular fashion (toddler t-shirts) and integrate circularity practices in the existing production process. It has been found that approximately 2238 pieces of circular products (CP) can be produced from the 218.6 kg surplus fabric, 212.13 kg reusable cutting waste and 210 reusable rejected cut panels. The approach followed in the study has presented the shortest loop of the circular economy consisting of the stages of gathering, sorting, redesigning, re-cutting, and sewing process. The investigation further demonstrates that, concerning ecological sustainability and economic feasibility, the direct reutilization of pre-consumer waste of cutting sections could prove more efficient than recycling, landfilling, or incineration.

1. Introduction

Modern consumers' high demand and consumption structure variance for fast fashion have been producing textile waste extensively (Marshall and Farahbakhsh, 2013; Niinimäki et al., 2020; Ütebay et al., 2020). The textile-apparel-fashion industry produces pre-consumer waste (material waste) at every stage of processing. Dropping, kitty, dust, noil, pneumafil, kirchi, lapetta, sweeping waste etc produce in spinning and weaving section generates sizing waste, knot, gaiting or tying-in waste, selvedge waste, chindi, and beam residual waste (Goyal, 2021). Doctor and Khatwani has pointed out different types of apparel waste like swatch waste, cut and sew, end of the roll, sampling yardage, damaged material, leftover materials, rejected apparel and unsold clothing (Doctor and Khatwani, 2022). Mominur Rahman (2016) reported that 26.5 % of waste is generated in an apparel factory in Bangladesh during knit t-shirt production, whereas 13.57 % is the unavoidable cutting section waste. After investigating ten clothing factories in Narayanganj, Bangladesh, (Masud Alom, 2016) discovered that cutting is the predominant region of generating material waste in the apparel industry. Textile waste has been classified as post-industrial, pre-consumer, and post-consumer waste. Cutting section waste (fabric left-over, cutting waste, excess fabric, spreading loss etc.) is the pre-consumer waste (Vadicherla et al., 2017; Cao et al., 2022). This unwanted massive fabric waste produced in the cutting section has become a concerning issue as material cost accounts for the maximum share of apparel costing (Bilgiç and Baykal, 2017). Conducting materials stream mapping in the textile-apparel production chain, researchers have found that 0.70 USD has been lost in every piece of apparel export due to textile-apparel material waste (Khairul Akter et al., 2022). Approximately 87 % of global textile waste is managed through landfilling, which is responsible for increasing solid waste. 90 % of this waste can be converted into value-added economic items through reuse and recycling procedures (Moazzem et al., 2021). The environmental price of this enormous waste is equally substantial which negatively affects the environment when incinerated or sent to landfills contributing greenhouse gases emission (Bizuneh and Tadesse, 2022). Incineration of

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material waste produces ash and carbon dioxide gases as it generates heat energy (Awasthi et al., 2019). During the materials processing stages, textile factories produce many toxic substances, considered chemical waste, resulting in different diseases. Toxic chemicals mixed with air and water (especially during dyeing) create environmental damage. Textile material waste also clogs rivers' flow and drains and consumes land space during disposal (landfill), leading to environmental pollution (Bick et al., 2018; Sivaram et al., 2018). Therefore, from the environmental perspective ethically established sustainable apparel business model is a robust idea (Niinimäki, 2015). Cucchiella et al. (2017) have presented an effective waste management hierarchy as following steps: prevention, reuse, recycle, recover, and at-last landfill. Landfilling of textile waste is the lowest-ranked strategy because landfilling causes the raw materials and efforts in a textile product permanently vanish from the total production and distribution network and results in a loss of economic value of the reusable material (Yalcin-Enis et al., 2019). The concept of circular economy is the best fit for solving the waste management problems in textile industries. (Nayak and Patnaik, 2021). Material reducing, reusing, recycling, recovering etc. principles are used in circular economy to sustain the quality of the environment and face the challenges of climate change (Kirchherr et al., 2017a). The use of the circular economy principles in apparel processing factories is emergent to reduce the negative impact of carbon emissions and fast fashion (Saha et al., 2021). Reusing a product is a more sustainable alternative to discarding it in the trash or landfill and it supports the circular economy with environmental conservation (Farrant et al., 2010; Fortuna and Diyamandoglu, 2017). According to a study of 45 million kg of waste reused annually in New York City, the amount of emission was reduced to about 122 million kg of carbon-di-oxide equivalent. (Lugo et al., 2020). The circular fashion approach supports the sustainable apparel business in addressing the massive waste produced by the modern textile and apparel sectors (Shirvanimoghaddam et al., 2020). The circularity in the production process encourages the reuse of cutting waste and prolong the flow of resources across the usage lives of the assets (Ballie and Woods, 2018). The circular economy can convert waste into new products through green practices (reduce, reuse, recycle) where waste is valorized, giving a repurpose. (Marques et al., 2019; Savini, 2019). Waste is reused, remanufactured, or recycled in the circular economy to mitigate its adverse effects on society, economy and the environment. (Pandit et al., 2020). Hence, incorporating discarded textile remnants into the production of circular fashion would substantially contribute to preserving ecological and economic sustainability.

Sustainable fashion brands especially sport and luxury businesses have incorporated a circular economy into their production process by utilizing and minimizing waste. For instance, Nike reduces waste production during processing, and the swimwear company (Davy J) uses the leftover fishing net and consumer garbage to produce recycled nylon yarn. (Moorhouse and Moorhouse, 2017). Modern customers prefer sustainable apparel (Nayak et al., 2019; Shrivastava et al., 2021; Vehmas et al., 2018) and the concept of "slow fashion" has recently garnered considerable attention from consumers, primarily due to its adherence to an ethical and sustainable production framework (Fletcher, 2010). The environmental implications of apparel play a crucial role in shaping consumer behavior towards purchasing trends (Zheng and Chi, 2015) and motivate them to pay more for green apparel (Pookulangara and Shephard, 2013). In line with the current demand, textile and apparel enterprises are actively seeking an avenue to alleviate the detrimental effects of clothing on the environment, augmenting their ecological consciousness and bolstering their attractiveness to consumers while safeguarding their revenue margins (Chakraborty, 2016). Circular strategies have gained superiority over the conventional linear fashion of take-make-distribution-consumption-waste due to their lower environmental impact, unlike the linear service life of a textile product (Mölsä et al., 2022). The closed-loop system of the circular economy prioritizes the preservation of materials throughout a sustainable production and consumption chain, resulting in decreased waste within the supply chain (Rathinamoorthy, 2019). Utilization of textile surplus and waste to develop fresh products may ensure the long-term sustainability of virgin materials, which would favor the environment (Sandin and Peters, 2018; Smith et al., 2017).

Recycling has recently emerged as the most popular waste management approach in the textile-apparel industry. It has been established that post-consumer waste can be repurposed through recycling techniques to create second-life products, which in turn, facilitate the recovery of the inherent value found in textile waste (Cao et al., 2022). Recent research highlights the potential benefits of utilizing pre-consumer textile waste as a means of effective waste management. Broega et al. (2017) proffer resolutions for reusing discarded fabrics by the textile sector via sustainable innovative commercial frameworks for the betterment of the ecological, financial, and communal aspects. As textiles possess a recyclability rate of nearly 100 %, no aspects of the textile and apparel industry must be squandered. Recycling pre-consumer textile waste is comparatively simpler than post-consumer waste, as pre-consumer waste does not entail hygiene and collection challenges like post-consumer waste (Lau, 2015). In Macedonia, an annual generation of 3377 tons of recyclable pre-consumer textile waste, namely apparel-cutting waste, emphasizes the urgent need for an initiative to recycle textile waste in the country after investigating the composition of the waste (Jordeva et al., 2018). High-quality products can produce through the reclamation of worth from pre-consumer waste, viz. fabric waste, predominantly through their reuse. (Johnson et al., 2020). Khairul Akter et al. (2022) suggest various territories to utilize the material waste of apparel industries following the principles of the circular economy and responsible consumption. The authors propose the production of smaller-sized apparel by repurposing larger cutting waste to enhance the value of pre-consumer waste rather than selling it in local markets for downcycling. Aus et al., (2021) investigate that fabric leftovers and textile waste generated in apparel production range from 25 % to 40 % of the total fabric used in the factory. The experiment shows that depending on the size, 50 % of material waste can be reused to produce new apparel, even up to 80 % in case of excess fabric. Sethi et al. (2017) have engineered ecologically aware commodities, including bedding, cushions, pillows, and shams, by means of reusing pre-consumer waste combining cotton, silk, satin, velvet, and polyester. Literature on textile waste predicts the potential of reusing and recycling fabric waste to produce new apparel for waste valorization to date but no empirical substantiation exists for the direct repurposing of pre-consumer waste from a specific design to fabricate novel merchandises for the circular fashion industry. The most salient gap found in the literature is that assessing a particular style to trace the waste types, sizes, total amount, quality and capacity of reusing pre-consumer waste to develop product for circular fashion has yet to be conducted. The implementation of straight reusing pre-consumer waste of cutting section rather than recycling it remains to be embraced in the circular fashion. Even though "Reuse" holds a higher position than "Recycling" in the waste management hierarchy, there remains a lack of evidence demonstrating its effectiveness as a waste management technique in the textile and apparel context. Reusing techniques advocate lowering waste and reclaiming materials value that is reaching the end of their lifespan in any particular stage (Kirchherr et al., 2017b). The direct utilization of pre-consumer waste in the circular fashion is undoubtedly a financially feasible method, as the expenses associated with recycling can be circumvented. Moazzem et al., (2021) states that the process of mechanically recycling all textiles fibers results in a process loss of 10–20 % and the chemical recycling of synthetic textile materials is 10–20 % more costly than that of virgin materials. This study aims to experiment a fresh approach to circular fashion applying the circular economy principle of 'reusing' to manage the pre-consumer waste sustainably generated in the cutting section of the apparel industry. The study will assess the pre-consumer waste generated in the cutting section of an apparel factory for a particular style produced. The present investigation is centered on reusing a particular style's waste, whereby the issue of

waste standardization (fabric weight, strength, color, shrinkage and other physical and chemical properties) can be overlooked, rendering this study distinct. After conducting a comprehensive examination of the byproducts generated during the cutting process, the reusable pre-consumer waste materials will be employed towards the creation of a CP that will facilitate the implementation of circular economy practices within the current apparel production system, particularly in the realm of circular fashion. The concept of the CP entails the creation of an optimally designed product that adheres to close-loop principles and prioritizes environmental sustainability (Mestre and Cooper, 2017; Van Loon and Van Wassenhove, 2018). The investigation will additionally exhibit a theoretical computation of conceivable CP that may emerge from the selected methodology. Ultimately, a recommended circular economy framework for using pre-consumer waste will be expounded upon to foster economic and environmental sustainability within the present apparel manufacturing process. Without jeopardizing environmental dimensions and ensuring maximum use of natural resources in apparel production refers environmental sustainability of apparel manufacturing and ensuring production quality consistency while lowering cost implies economic sustainability (Gbolarumi et al., 2021). Establishing a circularity or circular economy paradigm within the apparel manufacturing process for circular fashion shall evince the groundwork of environmental and economic sustainability. The outcome of the investigation shall serve the textile and apparel sectors in effectively managing waste engendered in the cutting sections of the apparel industry, congruent with the circular economy.

2. Materials and method

The cutting process for a specific style was traced to evaluate the pre-consumer waste for that style and explore potential reusable waste for circular fashion. This investigative work is conducted within a 100 % export-oriented knit composite factory in Dhaka, Bangladesh. The evaluation of pre-consumer waste produced in the cutting section for the designated style was executed between the months of February and March in the year 2022. A holistic outline of waste types, sizes, total amount, quality and capacity of reusing pre-consumer waste from a single spreading lay is presented here. The identical approach of gathering reusable waste from the entire style has been implemented throughout the cutting production. The CP from the reusable pre-consumer waste was developed in the product development department of the selected factory. The style traced in the study was a single jersey solid dyed t-shirt (boys) consisting of 75 % cotton fabric, 20 % recycled cotton, and 5 % lycra. The study collected various categories of waste from the chosen style to identify reusable pre-consumer waste and produce a toddler t-shirt, referred to as CP in the research. In the present methodology, pre-consumer waste of a particular style has been selected as it is anticipated that the waste would bear identical characteristics (fabric properties). Therefore, it is evident that ensuring the quality of raw materials, specifically their physical and chemical properties, to produce the CP would be a less challenging task compared to managing waste generated from various styles. An existing toddler t-shirt pattern from the product development department of the factory was used to develop the CP. Cutting section waste (remnant fabric after cutting and roll end waste), rejected panels (rejection due to needle marks, holes, knots, dye spots, oil spots, dirty spots, and other akin faults), and fabric damage waste (GSM cutting hole, shade problem, etc.) are collected from the selected style shown in Fig. 1. The faults are marked with a red arrow, as depicted in the accompanying images. The parts of the pre-consumer waste which were capable of being utilized more than once were repurposed as the raw materials of the CP.

The reusable cutting waste is sorted out after being tracked down, gathered, and measured for the weight and size of the cutting waste (Fig. 2). Waste collection bags are labelled in two criteria; cutting waste and other wastes (end roll waste, fabric damage wastes, and rejected panels wastes) depending on the size of the waste. Manual waste collection process and sorting process are conducted by two research assistants.

The front and back parts of the CP are prepared from the larger sized fabric waste (End roll waste) whereas smaller cut panels are reused to produce sleeves and necks of the shirt. Afterwards, the wastes are recut according to the pattern selected in the product development section.To assemble the cut panels four basic sewing machines are used listed in the Table 1.

The study also provided a 3D visualization of the CP utilizing CLO 3D software, displaying its fitting and draping. 2D digital patterns are initially created based on the measurement of manual patterns. Then, using the software's assembly methods, a baby dummy was chosen from the avatar area of the system to trial the virtual sample on the digital dummy. Before the simulation, digital stitching was used based on the

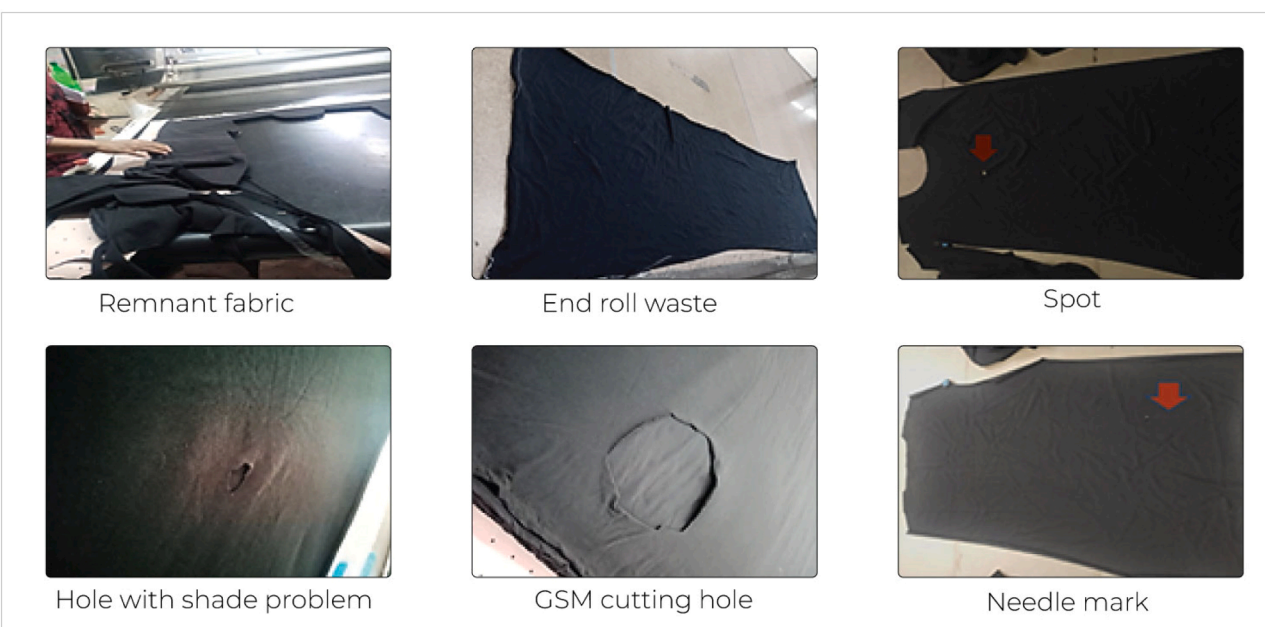

Fig. 1. Types of wastes produced in the study's particular style choice.

Fig. 2. Waste collecting process.

Table 1
Lists the machines that are used to manufacture CP with areas of application.

Machines	Areas of application
Four Thread Overlock machine of Yamato Brand of Model- AZ8120G-Y6DF-8 (4TO/L)	Shoulder and sleeve join, side seam join
Three thread overlock machine of JUKI brand of Model MO-623 (3TO/L)	Neck piping
Four Thread Flat lock machine of Pegasus S Brand of Model Pegasus W600 (4 T F/L)	Bottom and sleeve hemming
Single needle lock stitch machine of JUKI brand of model of DDL-8100e. (1NL/S)	Sleeve hem back stitching

placement of points on the avatar while also choosing the cloth's texture, colour, and other attributes. The study also demonstrated a theoretical calculation of potential CP that can result from the chosen approach. Finally, a proposed circular economy-led model has been presented in the research.

3. Results and discussion

3.1. Tracing of pre-consumer waste in the cutting section for the chosen style

The waste generating stages are identified during tracing the pre-consumer waste from the chosen style in the cutting section is tabulated in the Table 2. Here a comprehensive approach to gathering, quantifying, and classifying pre-consumer waste from a single spreading lay is presented. This process is viewed holistically to ensure a thorough and accurate assessment. The weight of the lay amounted to 60.4 kg, which was inclusive of 28 fabric plies. The ratio of M: L: XL: 2XL was determined to be 2:2:2:1; that is to say, there were 7 pieces per ply, and the total number of pieces in the lay stood at 196. While spreading the lay, a significant amount of end roll waste, precisely 2.50 kg, was detected. (Fig. 3-a) and approximately 2 kg wastes was reusable for smaller-sized apparel. The total cutting waste of the lay has been found 12.25 kg in the investigation having 80 % marker efficiency. Khairul Akter et al. (2022) has mentioned that the types of cutting section wastes varies depending on the waste size. It has been observed in the investigation that the sizes of end roll wastes are comparatively larger than the cutting waste. The minimum size of cutting waste was 1.5 cm width and 5.4 cm length while maximum size is 191 cm width and 228.6 cm length of end roll waste found in the investigation. Moreover, a significant amount of fabric is saved in the cutting section as bulk booking consumption is higher than the actual bulk cutting consumption and excess fabric delivery from knitting section, for extra knitting yardage, gsm variation, extra booking for order security, current fabric booking system etc. The extra fabric savings for the entire style has been explained in Table 4. Cutting waste sorting was the most challenging task in the investigation as they are smaller in size and irregular in shape. Majority of the wastes found unsuitable to reuse due to very uneven size. The non-uniform dimensions of the cutting waste from the cutting process underscore the imperative need for a creative conceptualization of CP, along with developing basic apparel that facilitates enhanced material efficiency. Only 2.8 kg cutting waste of total 12.25 kg cutting waste has been found reusable (Fig. 3- b,c) and rest of 9.45 kg cutting waste cannot reuse directly in this study. Minimum 30 cm width and 40 cm length cut fabric is considered as reusable cutting waste in this study because it is the minimum measurement of fabric required to produce sleeve part of the CP. So, reusable cutting waste definition will be varied from product to product depending on the requirement of the size of the desired CP. The magnitude of the cutting waste size presents a significant obstacle for this investigation, as the chosen CP of study involves a basic toddler t-shirt rather than a more elaborative apparel. Although irregularly shaped and smaller waste than the minimum requirement for selected CP was not feasible to reuse in this study, it could be repurposed in innovative design work for circular fashion. Rest of 9.45 kg cutting waste can recycle to produce recycled yarn later by the factory. Materials using efficiency maximization by reusing is the prominent strategy and recycling the last means of circular fashion hierarchy (Dissanayake and Weerasinghe, 2022). Circular fashion is an effective instrument for shifting from linear economy to circular economy practice. Reuse as raw material and reuse as product are two varieties of reusing process practice in circular fashion (Dan and Østergaard, 2021). This study practiced the reuse strategy as 'reuse as raw materials'.

Table 2
Tracing of pre-consumer waste in the cutting section.

Waste generating stages in the cutting section	Types of waste identification
Fabric Spreading	End roll and fabric damage waste
Lay Cutting (Auto and Manual)	Cutting wastes
100 % quality checking & panels replacing	Rejected cut panel waste
Re-cutting	Cutting waste

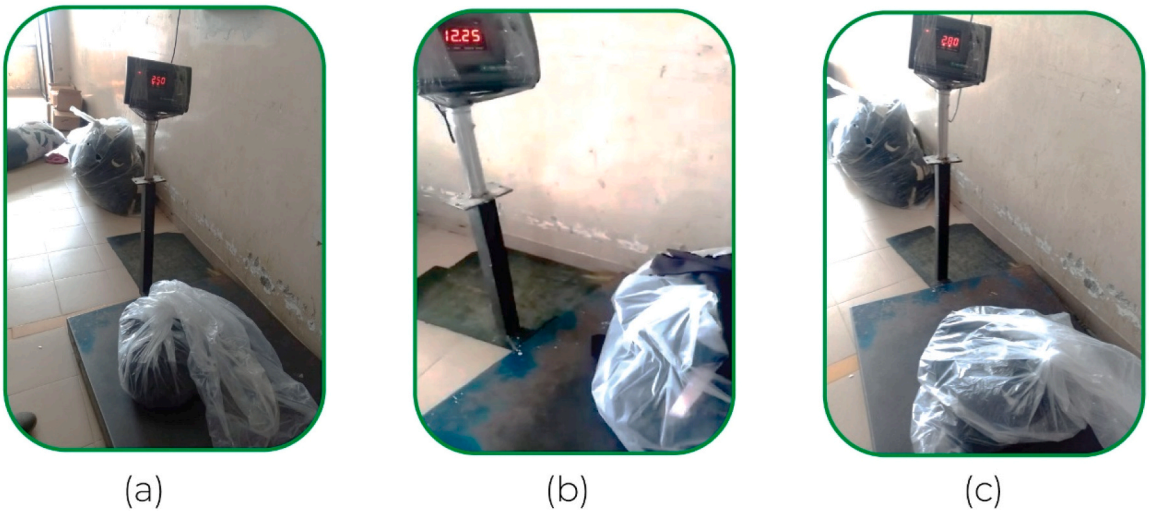

Fig. 3. End roll waste (a) cutting waste (b) reusable cutting waste (c) of the selected lay.

3.2. Panels cutting to assembly of CP

3.2.1. Body part

Body parts panels of the CP are prepared from the end roll wastes as they are comparatively larger in size than the other types of waste. 102.471 g of end roll wastes (6256 cm^2 fabric) are measured to make the body part panels shown in Fig. 4. Rejected panels can also be selected for the body parts depending on the size of the product.

3.2.2. Sleeve and neck part

Cutting wastes are selected for the sleeve and neck piping. Large pieces of cutting waste (average 30 cm width and 40 cm length) have been sorted among 2.8 kg of cutting waste for the sleeve and neck piping part of the CP using 72.589 gm waste fabric only.

Body panels are cut from the 102.471 g of end roll wastes and sleeve and neck piping are cut from the 72.589 gm of cutting waste (Fig. 4). Hence, total 175.06 gm (102.471 +72.589) of waste fabric is used to produce the toddler t-shirt (CP) from 4.8 (2.0 kg end roll waste and 2. 8 kg cutting waste) kg of reusable cutting section wastes. After re-cutting the waste the total weight of the cut panels (with allowance) has been found 89.878 gm (52.8 gm of body part and 37.078 gm of neck, sleeve part) and 85.182 gm of re-waste (waste from cutting waste) has been generated. This 48.66 % re-waste has no option except processed to produce recycled yarn as they are very tiny and irregular in shape. Then all cut panels are assembled (Fig. 5) by industrial sewing machines in the product development section of the factory. The operation breakdowns with respective machines are shown in the Table 3. The care label of original product was used in the CP as same fabric form cutting waste was utilized to develop the product.

3.3. Virtual fitting of the product

The draping characters of the apparel can be accurately portrayed in the 3D clothing models or avatars as like natural draping on human model (Duan et al., 2019) Virtual fitting and draping limitations and accuracy level is still being studied, but it is widely getting acknowledge to the today's consumer, industrial and researcher fields than physical fitting trial (Hu et al., 2019; Lee and Park, 2017; Lee et al., 2013; Porterfield and Lamar, 2017; Song and Ashdown, 2015). The virtual fitting of the developed CP has been shown in the Fig. 6.

3.4. Calculation of potential CP that can result from the chosen approach

The CP of this study has been developed from a single spreading lay waste. The value of total amount of fabric savings, roll end waste and cutting waste was investigated in the study (Table 4) to find out the

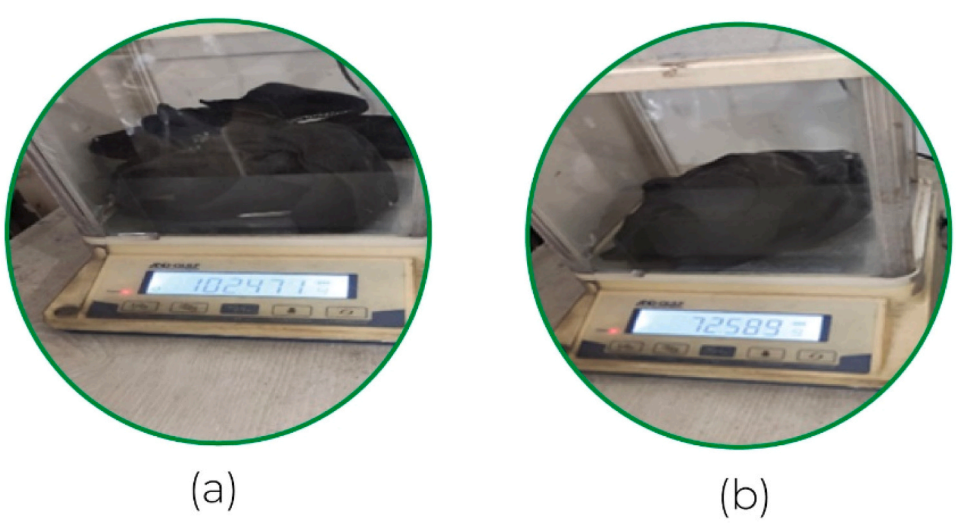

Fig. 4. Selecting and measuring of end roll waste piece to prepare body panels (a) and cutting waste for sleeve and neck piping (b).

Fig. 5. Panels cutting of the CP.

Table 3
Operation breakdown of the CP.

Circular Product (CP)	Operations with respective machines*
	Shoulder join (4TO/L) Neck piping make (3TO/L) Neck join (4TO/L) Neck tack (1 N L/S) Sleeve hem (4 T F/L) Sleeve & body match (Manual) Sleeve attach (4TO/L) Care label attach (1NL/S) Side seam (4TO/L) Sleeve tack (1NL/S) Bottom hem (4 T F/L)

*Machine details are shown in the Table 1

approximate value of potential CP (toddler t-shirt) can make from the pre-consumer waste of the chosen style. Although cutting section waste is unavoidable, the roll end waste generates in fabric spreading because the marker's length is fixed for a lay, but there are variations in the length of each fabric roll. (Aus et al., 2021) and cutting waste varies from style to style. Critical product generates more cutting waste than basic product because of small pattern piece increases or the use of multiple fabrics in different colours or constructions (Haque, 2016). As a result, depending on the marker's efficiency and style, the amount of promising CP from the cutting section waste will vary. More efficient markers will produce less cutting waste (Enes and Kipöz, 2020), reducing the quantity of CP. The order quantity and waste summary of the selected style has been tabulated below.

Order Quantity: 21003 pieces.

Total Apparel cut: 21930 pieces (927 pieces extra cut or overproduction*).

*Extra cut is the factory policy for order security like, cutting rejection, sewing rejection etc.

During the initial day of cutting production, 1176 pieces of clothing were cut out, with 278 kg or 840 m of fabric required and 22 m of fabric balanced from savings and roll end. Initially, 13 m of fabric were saved and delivered from the fabric production department, and 9 m of roll end was generated during the spreading stage. This saved fabric was utilized in re-cutting, resulting in the final balance of fabric being 2 m,

Fig. 6. Virtual fitting of the CP.

Table 4
Waste summary of the selected style.

Date	Cut no.	Pieces cut	Actual fabric used (kg)	Actual fabric used (m)	Fabric savings (m)	Roll end (m)	Re cut (m)	Final savings (m)	Reusable Quantity (from final savings) (kg)	Cutting waste (kg)	Reusable cutting waste quantity (kg)
01/02/2022	1	1176	278	840	13	9	20	2	0.5	55.36	12.3
01/02/2022	2	1008	231	691	40	19	22	37	11	45.85	10.5
10/02/2022	3	252	55	162	21	2	6	17	5	10.5	2.1
10/02/2022	4	1404	318	975	43	10.3	13	40.3	10.2	64	14
10/02/2022	5	1392	314	932	77	8	20	65	20	63.68	12
10/02/2022	6	756	172	518	30	5.95	11	35.95	11	33.25	6.5
10/02/2022	7	1440	331	982.6	61	13.61	18	56.61	17.9	65.2	14
10/02/2022	8	168	43.3	122.48	-1	6	0	5	1	6.89	1.2
13/02/2022	9	1200	273.37	800.1	70	3	16	57	17.5	55.45	11.65
13/02/2022	10	78	15.5	48.75	8	0	0	8	1.5	2.9	0
13/02/2022	11	1092	260.7	763.1	29	10	10	29	9	52	10.6
13/02/2022	12	1512	351.2	1023.2	73	18.5	16	75.5	22	71	16
13/02/2022	13	1584	364.1	1076.7	72	7	10	69	21	73.5	15.6
13/02/2022	14	612	143.3	421.7	22	8	12	18	5	29	5
14/02/2022	15	1164	275.8	808.3	36	16	8	44	14	55.8	12.3
14/02/2022	16	648	150.9	435.1	35	8	10	23	7	30.5	7.1
24/02/2022	18	1572	349.7	1076.1	64	9.18	20	53.18	17	70.9	16.3
24/02/2022	19	1644	375.1	1143.3	49	7	12	44	12	76	12.63
24/02/2022	20	1332	302.2	931.3	34	9	2	41	10	60.5	13.9
24/02/2022	21	792	190.2	596.7	-23	14.2	0	-10.8	0	38.5	8.8
02/03/2022	22	424	101.6	301.8	6	7	0	13	2	20	1.5
02/03/2022	23	392	93	278.6	6	3	0	9	2	18.5	4.25
02/03/2022	24	64	15.4	43.44	3	4	0	7	2	8.8	1.7
02/03/2022	25	224	56.3	170.87	-8	3	0	-5	0	10	2.2
Total		21930			760	200.7	226	733.74	218.6	1018.08	212.13

with half a kg of fabric being deemed reusable for CP after waste assessment. The total cutting waste was 55.36 kg from the 278 kg of fabric used in the cutting stage, but only 12.3 kg were reusable based on the cut panel size requirement of the CP developed in the study. This waste assessment process was followed throughout the entire cutting production of the selected style. Data indicates that 218.6 kg of recoverable extra fabric and roll-end waste and 212.13 kg reusable cutting waste were discovered at the end of the production. The table shows that 760 m of fabric were wasted in the cutting section, which is caused due to the current order structure found in the investigation. The buyer is the sole decision-maker in the process, attributable to Bangladesh's pre-order-based manufacturing technique for apparel. (Hasan, 2017). This study discovered that the buyer might modify the requirements and pattern forms after ordering the bulk fabric, which leads to less consumption than anticipated and results in fabric surplus. Sometimes actual bulk fabric width is bigger than the marker width found in the investigation because both sides of the fabric (width-wise) are attached to the machine frame throughout various fabric finishing processes. As a result, a small or continuous hole appears on the fabric's width edge that must be avoided during cutting. Additionally, cutting from both of the fabric's width-wise edges allows lay operators to shave off some length, making the panels a sharp edge. Another significant cause of excess or shortage fabric is the unit of the fabric booking. At present, factory books fabric in kg rather than in linear yardage discovered in the analysis. If GSM (gram per meter square) is getting low, length will be more than required and vice- versa. Moreover, the knitting section knits more than the order quantity for the safer side, as there could be fabric faults in production. This excess fabric is delivered to the dyeing section and then to the cutting section of the factory, resulting in wastage at the end of the production. Reusable fabric savings can be used to make body parts of the CP. As body parts of a single product consumes 102.471 g of fabric or 0.102471 kg fabric, so body parts of (218.6 kg/0.102471 kg)= 2133.2864 ≈ 2133 pieces apparel can cut from this significant excess fabric and roll end waste. Furthermore, even though there were 270

total rejected panels for that design in the cutting section, 105 pieces of body parts could be cut from the 210 pieces of rejected panel components discovered during the investigation after 100 % inspection of the rejected panels. The remaining 60 pieces could not be reused because of the location of the faults. Body parts of total (2133 +105) = 2238 pieces CP can develop from the reusable waste. Sleeve pairs and neck piping can make from the 212.13 kg reusable cutting section waste. 72.589-gram or 0.072589 kg fabric is needed for the one-sleeve pair and neck. So, (212.13 kg/ 0.072589 kg) = 2922.34 ≈ 2922 sleeve pair and neck can prepare from this cutting waste. As the body parts of 2238 pieces of apparel can be cut from the waste, only 2238 sleeve pairs and 2238 neck piping are required. The remaining 690 pairs were considered re-waste in this study because there is no way to put them back into circulation.

4. Circularity in the proposed approach

Numerous entities and stakeholders are actively working to incorporate sustainability in textile waste management. (Chavan, 2014). Some sustainable business norms include increasing material efficiency (by minimizing waste and manufacturing neatly), generating value from waste, using a specific business strategic plan, giving the environment and society a higher priority than revenue, and creating green products through waste reuse or recycling (Pal, 2017). Certain renowned clothing companies C&A, H&M, Levi Strauss &Co, Patagonia etc. are promoting sustainability through circular fashion (Rathinamoorthy, 2019). If apparel factories make an effort to repurpose cutting waste, the Bangladeshi apparel sector can promote circular fashion on the international market because the circular economy's industry is increasingly centered on recycling and reusing products (Kumar and Carolin, 2019). C&A brand practicing C2C (cradle to cradle) - a circular fashion cycle focusing on the post-consumer waste to introduce zero waste strategy. This strategy implies after use of high quality products consumer can return back the product to C&A suggested collection points. Then good quality and useable raw materials recollect to reuse in production (Fig. 7).

The diversity in the cost, lead time, and performance characteristics of the recycled product is a substantial limitation of the circularity approach followed by the C&A brand. Creating recycled apparel requires time- and money-consuming processes, including waste opening, re-spinning, re-knitting, and re-dyeing. A study's findings show that it costs USD 4.01 per kg to make recycled yarn in Egypt from 11 % yarn waste (2 % labor cost, 3 % electricity and additional material expense separately, 14 % capital cost, and 67 % raw material cost). Creating yarns from 8 % waste costs USD 3.28 in the United States (16 % labor cost, 5 % electricity and auxiliary material expense separately, 19 % capital cost, and 47 % raw material cost). Similarly, Italy and Turkey cost 4.59 USD and 3.23 USD, respectively, to make 1 kg of recycled yarns from 8 % and 6 % waste. (Wanassi et al., 2016).

If cutting section waste can be reused without further processing to generate a circular fashion, the expenses (Table 5) and time required in recycling processes can be avoided. "Reusing" rather than "Recycling"

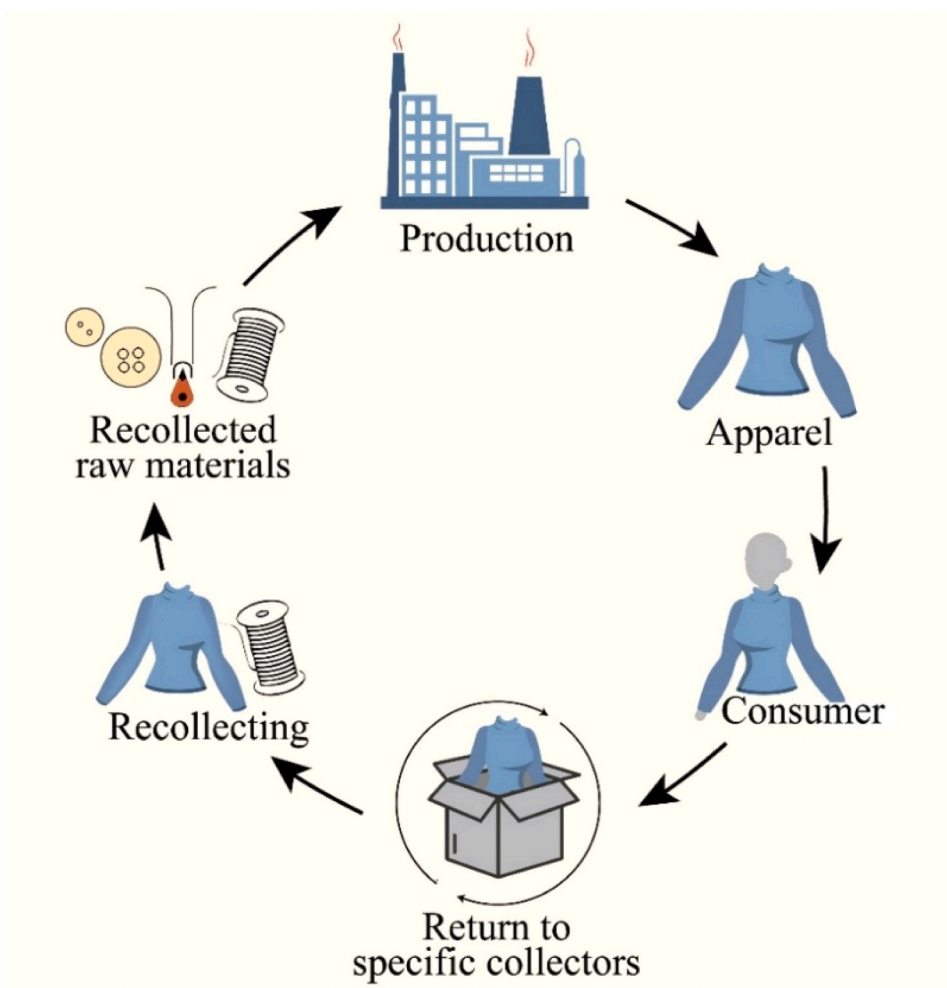

Fig. 7. Circular economy practice of C&A buyer (Cradle-to-Cradle Describes a Circular Economy in Which Products Are Recycled without Waste. Find out How C2C Works Here, n.d.).

will be more cost-effective since no spinning, knitting, or dyeing stages are needed in the study's methodology as the manual collection, sorting process and CP design based on waste sizes were the major steps of straight reusing of cutting waste. Based on a comprehensive inquiry into the fashion supply chain of Hong Kong, it has been determined that using pre-consumer waste for material cost reduction is a viable option because this approach allows utilizing waste as economical raw materials that can be repurposed for the development of new apparel designs (Lau, 2015). In terms of performance properties, recycled yarn performs less than virgin materials. Yarn made of virgin cotton possesses greater tensile strength and elongation than virgin-cotton-and-recycle-cotton mix and 100 % recycled cotton. Fabrics made of virgin cotton provides higher bursting strength (more than 600 kPa) and lower pilling grade (below grade-3) than recycled cotton. (Yuksekkaya et al., 2016). Rathinamoorthy (2018) has also proved that bursting strength (BS) and pilling resistance value (PRV) are more in normally developed fabric (BS=160.8 PSI, PRV=3.2) compared to recycled fabric (BS=63.6PSI, PRV=1.2). Additionally, length (LWS %) and width (WWS %) shrinkage percentage is less in virgin fiber's fabric (LWS %= 2.34, WWS %= 0.62) than in recycled fiber's fabric (LWS %= 4.22, WWS %= 0.92). On the other hand, performance characteristics of the CP developed in the study will be equivalent to that of the original product as no processing was required for the reusing of cutting waste. So, the cost associated with fabric quality examination for the CP could be avoided as it was completed once for the chosen style. Comparing and considering the significant limitations of recycling fiber's properties, cost and time required in recycling, it has become necessary to pay attention to the straight use of cutting waste circularly. In this context, the apparel factories can use the study's methodology in the present apparel production system. Implementing an inventive technique for sustainable manufacturing that facilitates the attainment of a circular economy within the realm of apparel production entails developing CP utilizing pre-consumer waste derived from the cutting section - an undoubtedly groundbreaking notion. Establishing a competitive market for apparel manufactured from pre-consumer waste presents the potential to create fresh business prospects that support the standards of economic sustainability (Schmutz and Som, 2022). Furthermore, employing pre-consumer waste material will decrease the waste management expenditure incurred by the factory. Consumers today who are concerned about the environment would welcome these circular products since they come from a sustainable and ethical production system emphasizing circularity in the ongoing production process. The attainment of an environmentally-friendly reputation coupled with a positive financial outcome will provide manufacturing facilities with a competitive edge in the marketplace (Fig. 8).

Currently, the factory sells the cutting waste referring "Jhut/Jhoot/Jhuta"—to the local traders. Jhut is the term for materials wasted in the textile and apparel industries, such as unused fiber, yarn, fabric, small-sized cut panels etc. (Khairul Akter et al., 2022). In Bangladesh, the amount of waste sold as Jhut is rising daily, and huge informal markets have emerged in many regions of the nation. (Bhuiya, 2017; Tabassum et al., 2017; Today, 2020). It has been reported that knit fabric Jhut price and amount of export is higher than woven fabric since further processing is easier on knit Jhut (Pensupa, 2019; Today, 2017). This study explores that the factory sells surplus fabric after production completion because there isn't any proper planning or initiative for this recoverable waste. To make the current production process more sustainable and complying with the circular economy, an appropriate model for this substantial material waste is required. Developed new apparel using this unavoidable waste, apparel factories can open a new sustainable business strategy as it ensures a high rate of materials utilization and decreases waste generation. Manufacturing CP from pre-consumer waste from the cutting section will offer a new dimension of circularity practice in the apparel industries emphasizing economic and environmental sustainability.

Table 5
Cost comparison of fabric made from virgin material and recycled fiber.

Cost aspects	Per Kg fresh fabric cost, cutting waste of which collected for the recycling Normal process followed- (Rathinamoorthy, 2018)	Per Kg recycled fabric cost Recycling process followed- (Rathinamoorthy, 2018)
Yarn	$ 3.358	$ 2.482
Knitting	$0.248	$ 0.248
Dyeing	$ 1.752	$ 0
Washing	$ 0	$ 0.876
Compacting & finishing	$.102	$ 0.102
Total	$ 5.460	$ 3.708

5. Conclusion

Consumers today are much more concerned with the clean and sustainable manufacturing of their clothing, and companies are working to improve the sustainability of their waste management practices. Implementing circular fashion by repurposing pre-consumer waste from the cutting section presents an ecologically sustainable approach to managing cutting waste in the global apparel industry. Such a method is poised to yield a twofold benefit of enhancing factory profits while mitigating the environmental impact of cutting waste. This study has traced the pre-consumer waste produced for a specific style in the apparel factory's cutting section. A CP has been developed in the research after gathering, sorting, redesigning, re-cutting, and sewing. It has been discovered that significant amounts of reusable and recyclable waste are produced. After manufacture, it was revealed there was 218.6 kg of recoverable surplus fabric. Out of the 270 panels that were cut following rejection, 210 are still functional for CP. Of 1018.08 kg of cutting wastes from the 21003-piece order, 212.13 kg have a straight reuse value. Due to size diversity and defect types, recycling is the only alternative for the re-waste produced in developing CP. Calculation of total cutting waste has showed that approximately 2238 pieces of CP (toddler t-shirt) can be produced from the cutting wastes of a specific order although the amount depends on the type, quality and size of wastes. If factories implement this approach of circularity in the existing production system on a regular production basis; incineration of the waste can be avoided (environmental sustainability), and additional profit margin (economic sustainability) will be included in the factory revenue. Selling and informal trading of cutting waste can also be escaped by implementing this profitable, smart, and circular way of managing waste. However, the response of the actual buyers and consumers still needs to be revealed. Besides, initial investment and setup costs can create challenges as it is a new product segment. If factories can invest in additional manufacturing costs, maintaining the quality of the products and circular fashion consumers are satisfied with circular products, pre-consumer waste of the cutting section could be a new door of profit generation for the apparel industries of Bangladesh.

The process of tracing the cutting waste and the design and production of the CP is conducted on a relatively small scale in the selected factory. However, the potential for upscaling is feasible through the development of standardized protocols and guidelines for the tracing and management of cutting waste. Collaboration with established entities within the circular fashion industry can also be leveraged to enhance the expertise, resources, and infrastructures necessary for scaling up the utilization of pre-consumer waste for circular fashion initiatives of the factory.

This study only focuses on developing toddler t-shirts utilizing pre-consumer waste of a specific style. The potential research avenue lies in the creation of an innovative and larger-scale product through the utilization of pre-consumer waste.

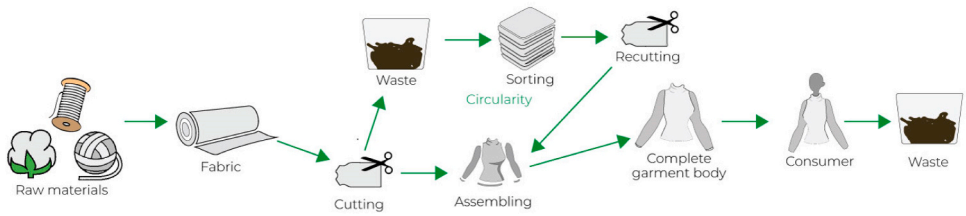

Fig. 8. Circular economy-led model for cutting section waste of the apparel industry.

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CRediT authorship contribution statement

Upama Nasrin Haq- Conceptualization, Methodology, Original Draft writing, reviewing, editing and Data analysis. **S. M. Rakifull Alam-** Investigation, Data collection, Original Draft writing and data visualization.

Declaration of Competing Interest

There was no conflict of interest to declare.

Data Availability

The authors do not have permission to share data.

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