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Zero-Waste Pattern Cutting (ZWPC) to tackle over Sixty billion square metres of Fabric Wastage during Mass Production of Apparel

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Abstract:

This paper for the first time demonstrates the application of the concept of Zero-Waste Pattern Cutting (ZWPC) into mass production of apparel to tackle over 60 billion square metres of scrap fabrics being produced by the fashion industry annually. A strategic framework for implementing ZWPC for multiple sizes of clothing was first developed, then applied and tested on two styles of garments in multiple sizes. Digital pattern cutting and marker making techniques were used to design and cut pattern pieces of different sizes of garments for same style. Physical prototypes were made, and wearer trials were done to check the fit of clothing. It was found that over 98% of fabric utilisation was achieved for both styles, while in traditional industrial practice over 85% is considered impossible. This indicates that the strategic framework for implementing ZWPC in mass production of clothing is effective to result in a much cleaner production. This leads to the development of a ZWPC paradigm for the apparel industry and a novel apparel design process. This framework can be further improved by testing with many different styles of garments being manufactured by the fashion industry today. This will bring a huge practical implication to the apparel industry by offering a leaner and cleaner production strategy.

Keywords: Zero-Waste Pattern Cutting (ZWPC), Carbon footprint, Fabric, Mass production, Pattern cutting, Marker making, landfill

1. Introduction

Fashion industry generates wastes both in pre-consumption and post-consumption stages, which mark significant environmental footprint (Hawley, 2006; Gam and Banning, 2011; Wang et al., 2015; Parisi et al. 2015; and Oztuk et al., 2016; and Yan et al., 2016). Just at the garment manufacturing stage, around 15% of the fabrics remains unused and are thrown away as solid waste destined for landfills (Cooklin, 1997; MacQuillan, 2011, Rissanen, 2011, Rosebloom, 2010; Townsend & Mills, 2013). The traditional pattern cutting process, a technical drawing process to illustrate every component of a clothing item on paper or digital environment to facilitate cutting of fabrics, considers the garment pattern pieces as irregular shapes, which cannot be placed next to each other like a jigsaw puzzle. Therefore, it cannot make the full use of the length and width of a fabric spread. According to an estimation done in 2012, around 400 billion square metres of fabrics are used for garment manufacturing across the world (Gungnami and Mishra, 2012; Kirchain, et al., 2015; Ditty, n.d.; FFM, 2018). This is continuously rising with the rise in demand of clothing due to the ongoing trend of population growth globally. This means about 60 billion square metres of fabrics or more simply turns into a waste during garment manufacturing around the world. This is not just a waste of fabrics; rather this is also the waste of fibres and yarns used for making those fabrics, dyes and chemicals produced and used in colouration of those, and the valuable time, labour and money invested behind all these processes and is responsible for a huge adverse impact on environment and corresponding carbon footprint (Wang et al., 2015; Parisi et al. 2015; and Oztuk et al., 2016). According to Yan et al. (2016), the total industrial carbon footprint of fabrics varies from 3.65 to 14.07 kg CO_2/kg depending on fibre types, processing techniques involved, and dyes and chemicals used. Usually the weight of commonly used fabrics in the apparel industry varies from 100 to 400 grams per square metre, which makes around 10 to 2.5 square metre of surface in 1 kg of fabrics. Based on this calculation, the weight of about 60 billion square metres of fabrics will vary between 6 and 24 billion kg. Connecting this with the carbon footprint provided by Yan et al. (2016) gives an estimation of a carbon footprint ranging between 21.9 and 337.7 billion kg of CO_2 equivalent.

Zero-waste pattern cutting (ZWPC) is an approach, a concept and a design philosophy that aims to utilise the whole area of fabric within a given length for making one or more garments (Towsend & Mills, 2013; Niinimaki, 2013; Carrico and Kim, 2014; Rissanen and Mcquillan, 2016). However, this concept is not new. Traditional garments such as the saree, dhuti, lungi and kimono etc. are the examples of garments that follow the concept of ZWPC. Saree worn by women in Bangladesh and India is just a rectangular piece of fabric without any stich or seam. Similarly, dhuti and lungi worn by men in Bangladesh and part of India are a rectangular piece of fabric and a tube made of rectangular piece of fabric with only one side-seam respectively. Japanese kimono produces no waste in cutting process as all components are kept restricted to the width and length of the fabric used. Historic Greek chiton was also a rectangular piece fabric used to be tied with body with additional cord or tape (Rudofsky, 1947). During the pre-industrial era, European tailors and dressmakers always targeted 100% fabric utilisation as fabric used to be a very precious commodity that time (Burham, 1973). Among the twentieth century designers Claire McCardell from 1940s practiced zero-waste

(ZW) apparel design by use of rectangular fabric pieces sewn together and fitted with elastic bands (Rudosfky, 1947).

Mcquillan (2011) discussed four design practices that are based on ZWPC philosophy. They are tessellation, jigsaw, embedded jigsaw and multiple cloth approach. Carrico and Kim (2014) proposed a fifth design practice for zero-waste (ZW) apparel design, which they termed as 'minimal cut'. In tessellation method, one single regular shape, sometimes in different sizes, is repeated and fitted together with no gap, to make components of a full garment. The jigsaw method fits pattern pieces next to each other like a jigsaw puzzle, where the pattern pieces look similar to traditional pattern pieces, but they are placed next to each other to share same cut line with no fabric waste. Carrico and Kim (2014) mentioned citing Mcquillan (2011) that embedded jigsaw design followed the same approach of traditional jigsaw method except the former focused on designing multiple garments together. Following multiple cloth approach, different styles are cut on the same length of fabric to maximise fabric utilisation. This approach looks for design features of different style to make use of the shapes of leftover fabric pieces from style. Minimal cut is a design practice 'wherein the garment is designed through draping with limited cut made into and within the fabric" (Carrico and Kim, 2014, p.61).

Despite several methods of ZWPC have been explored as it has been mentioned above, they remain confined within the atelier environment for designing and making one or two garments at a time. There is no report so far or no demonstration has been made how they can be applied in mass production of clothing (Mcquillan, 2011; Towsend & Mills, 2013; Niinimaki, 2013; Carrico and Kim, 2014; Rissanen and Mcquillan, 2016). Townsend and Mills (2013) and Carrico and Kim (2014) conducted noteworthy studies on the application of ZWPC but their works focused on one or two designs with no more than one size. According to Niinimaki (2013), ZWPC can only be used in a limited amount of designs and fabric types, as it adds often unwanted bulk and fullness to the garment. It is also suggested that it should be limited to small-scale production due to its complexity, and her study did not address the possibility of going on the larger scale by identifying and dealing with associated barriers. Saedi and Wimberley (2018) explored the idea of designing in three dimension (3D) on a fashion mannequin rather than in two dimension (2D) on paper to merge the design and pattern cutting process into a single step. Again, this method has been found successful for one design in one size, however, the possibility of manufacturing the same design in different sizes connecting the mass production concept has not been explored. This emerges as a research gap in this field of knowledge. In mass production, pattern pieces of multiple sizes of same style are laid out on a marker plan to facilitate fabric cutting before assembling them together according to sizes to form garments. The aim of this study is to apply ZWPC in marker making of multiple sizes of garments targeting mass production. As multiple sizes of garments are considered for mass production, a mini collection of three different sizes for each style was planned for this work.

2. Methodology

In mass production strategy, same style is made in multiple sizes. Two common styles of garments: a pair of sweatpants (joggers) and a hooded t-shirt in three different sizes each were selected for implementing ZWPC technique. At first, a strategic framework was developed to systematically implement this technique in design, pattern cutting and marker making of the selected styles (see section 2.1). Patterns were created digitally using the Gerber AccuMark 10 system as digital pattern cutting offers easy manipulation of pattern pieces (Gray, 1998), accurate grading (Chase, 1997) and efficient marker planning (Carr et al., 2008). Initial pattern pieces were made within AccuMark pattern design system (PDS) using the measurements of size M presented in the tables 1 and 2. Using the measurements of other sizes and relevant grade values, grade rule tables were developed in the AccuMark PDS to grade the pattern pieces of both styles into other sizes. The pattern pieces were placed on the AccuMark PDS screen similar to a marker layout in order to facilitate pattern drafting by applying the ZWPC approaches as described in the next section (2.1) and to ensure maximum utilisation of fabric surface area. For doing so, the suitable commands within the Line tools and Piece tools under the *Create* Menu; the Move, Rotate and Flip commands within the Piece Action tools under the *Modify* Menu of PDS screen were used. Finally, the marker-making tool 'Gerber Easy Order (GEO)' was used to calculate the fabric utilisation for the patterns designed.

Table 1: Measurements and grade chart for hooded t-shirt

Point of measurement	Measurements (cm)			Grade Values		
	Small	Medium	Large	Small	Medium	Large
½ chest	45.5	50.5	55.5	-5	0	5

length	65	67	69	-2	0	2
overarm/shoulders	42	43	44	-1	0	1
biceps	17	19.5	22	-2.5	0	2.5
back neck width	19	17	18	-1	0	1
back neck drop	2.5	2.5	2.5	0	0	0
front neck drop	8	8.5	9	-0.5	0	0.5
hood height	42	43.5	45	-1.5	0	1.5
hood width	17.5	19	20.5	-1.5	0	1.5
hem	45	50	55	-5	0	5

Table 2: Measurement and grade chart for Joggers

Point of measurement	**Measurements (cm)**			**Grade Values**		
	Small	Medium	Large	Small	Medium	Large
½ waist (relaxed)	45	50	55	-5	0	5
½ waist extended	60.5	65.5	70.5	-5	0	5
hem @ cuff	44.2	45.2	46.2	-1	0	1
front rise	28	29	30	-1	0	1
back rise	27	29	31	-2	0	2
inner leg	79	80	81	-1	0	1

2.1 Developing strategic framework

Figure 1 presents the strategic framework developed to implement ZWPC for multiple sizes of garments. The first step was to identify design features for the selected styles considering the ZWPC concept. The next step was to start pattern cutting, grading and marker planning simultaneously. These are done in isolation in traditional clothing design process (Tan and Hoon, 2016; McKelvey and Munslow, 2012; James et al.; 2016). Fashion designers start with design illustration based on their own research and imagination. They do not communicate or collaborate with pattern cutter at this stage (James et al., 2016). However, this isolation does not support the concept of ZWPC. Tan and Hoon (2016) suggested that the collaboration and an overlap of understanding between pattern cutters and designers could help create more efficient designs. Therefore, the approach of this study was to design garment and create pattern pieces for the same garment simultaneously in a seamless process. Two ZWPC techniques identified for this work were the **embedded jigsaw method** and **multiple cloth approach** (see section 1). The multiple cloth approach was adapted and tested for different sizes of same design to be cut from the same fabric and termed as the "**multiple size approach**" hereafter.

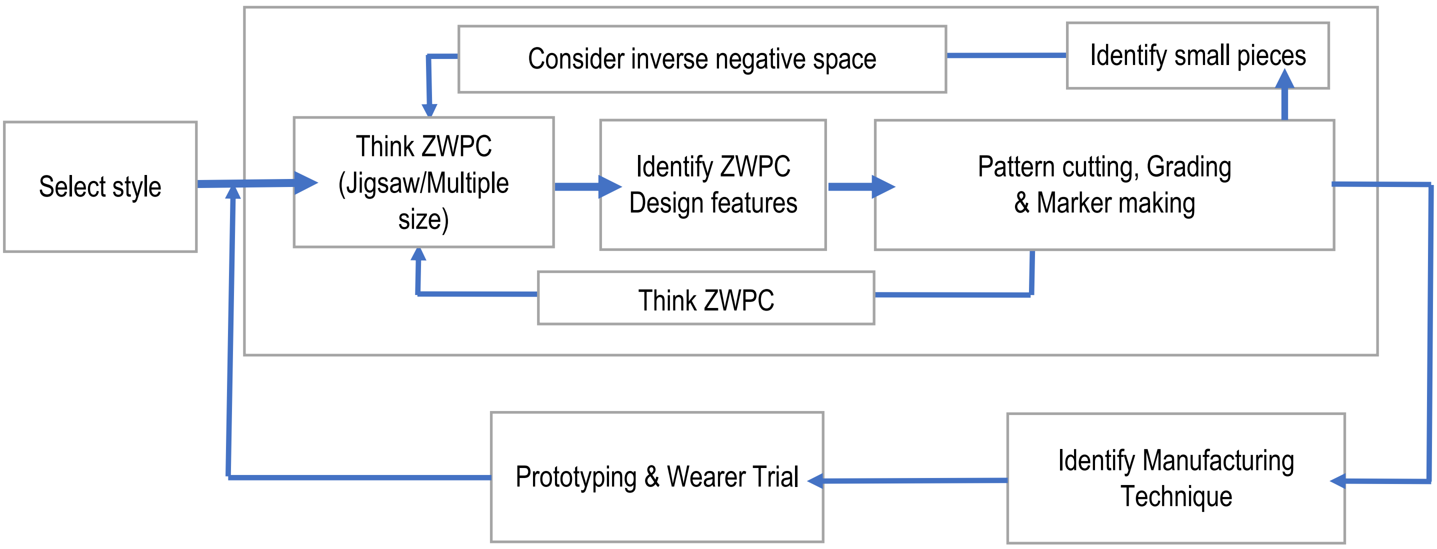


Figure 1. Strategic Framework for implementing ZWPC for multiple sizes

Once the appropriate design features are identified, pattern cutting, grading and marker making were done simultaneously. Traditionally pattern design and marker making are done in two separate apps or software modules. However, for implementing ZWPC, pattern pieces are graded immediately, and they are laid side by side to make marker within the PDS. Embedded jigsaw and multiple size approach were applied while maker making. The unused spaces in traditional pattern cutting (hereafter termed as ***negative spaces***) were utilised to make different small components such as pockets, bindings, hoods, hood decorative features, shaped dropped hems, underarm and crotch gussets, brand labels and zip guards etc. It was found that the negative spaces from large size patterns were useful to make different small components for small size garment and vice versa. This is termed as the "***inverse negative space concept***". Using self-fabric for making features such as brand labels and bindings is an excellent way for a high street brand to save on costs of getting additional trims and labels.

True ZW apparel manufacturing also much depends on the manufacturing techniques chosen for assembling cut pieces of fabric together. For knitwear, four-thread overlock stitch (class 514) is commonly used. An overlock sewing machine is provided with a fabric trimmer, which trims off 2-4 mm of fabric along the edges it sews together. Therefore, the gap between needle and trimmer was adjusted to over 5mm so that it does not trims off any fabric when a seam allowance of 5mm is maintained, thus ensuring no waste at sewing stage.

2.2 Implementing ZWPC for multiple sizes

2.2.1 Style 1 – Sweatpants

While identifying the design features for this style (see Figure 2), geometrical shapes and lines, as opposed to curved lines similar to those usually found in crotch and inner legs (see Figure 3a), were taken into consideration to apply ZWPC jigsaw principle. A different crotch shape (see Figure 3b) was chosen for this style inspired from harem pants, as they provide a lot of room for movement. Use of straight lines and near rectangular pieces allow full use of fabric, making the jigsaw method much easier to apply. The use of straight lines did not distort the shape of the garment or decrease its functionality, as a few different gussets (Figure 3d) were added in strategic areas such as the inner legs and side hips. This alongside the elasticated waistband and stretch leg cuffs provided good shape as well as added function and ease to the garment.

Following the strategic framework (Figure 1), pattern cutting, grading and marker planning are done simultaneously in the PDS window (see Figure 3c). Figure 2 and 3d represent the coloured illustration of all pattern pieces for better understanding for the whole process.

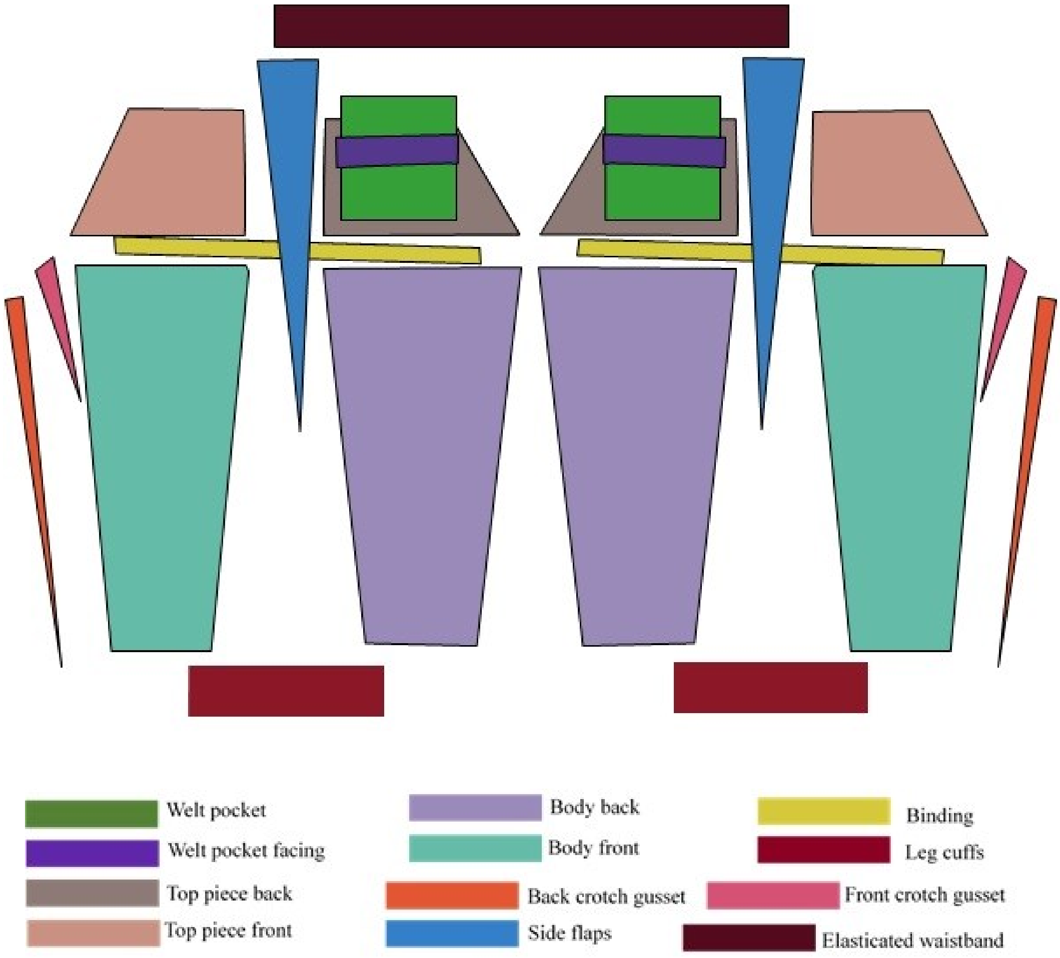


Figure 2: Technical design of Sweatpants

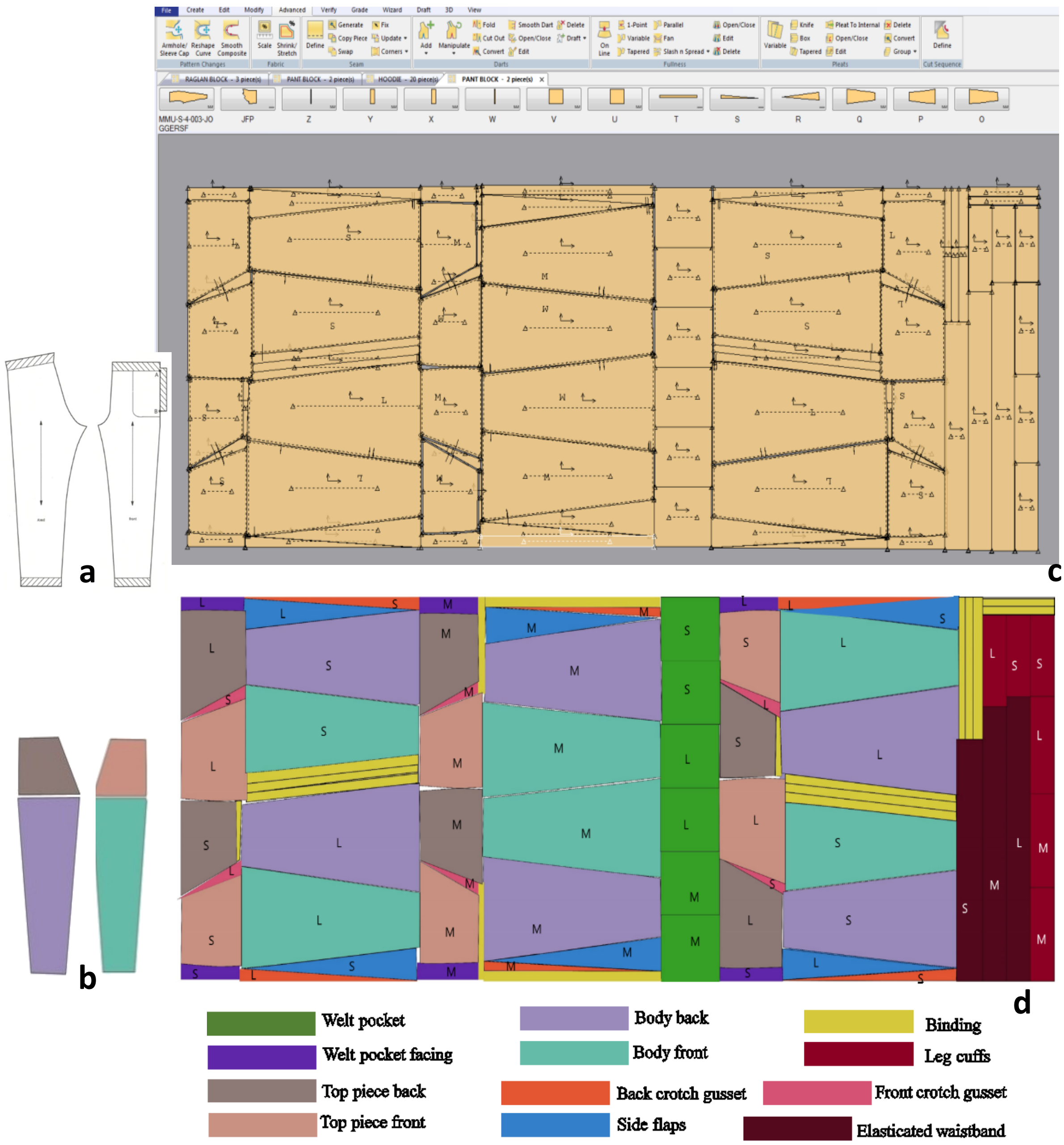


Figure **3**: a) Silhouette of traditional patterns for trousers (Aldrich, 2011), b) silhouette of the chosen design, c) marker planning in the PDS widow, d) Coloured illustrations of all pattern pieces.

2.2.2 Style 2 - Hooded t-shirt

For the hooded t-shirt, the similarity between the underarm shape and the hood shape was first explored for the best use of fabric (see Figure 4 and 5b), unlike traditional pattern of t-shirt presented by Aldrich (2011) as it can be seen in the figure 5a. A kimono style sleeve (see figure 4 and 5b) was chosen, as the negative space created from the underarm shape was similar to a hood shape. Figure 5b shows how the negative spaces from the body and arms were used to create hoods. Other triangular pieces, created from the slanted edges on the shoulder were turned into side gussets (see Figures 5c and 5d), which aided the garment with extra ease for movement. The hood inserts were not uniform throughout the different sizes (Figure 5d), but pleating was used during sewing to bring the inserts to the right length. Figure 4 and 5d represent the coloured illustration of all pattern pieces for better understanding for the whole process.

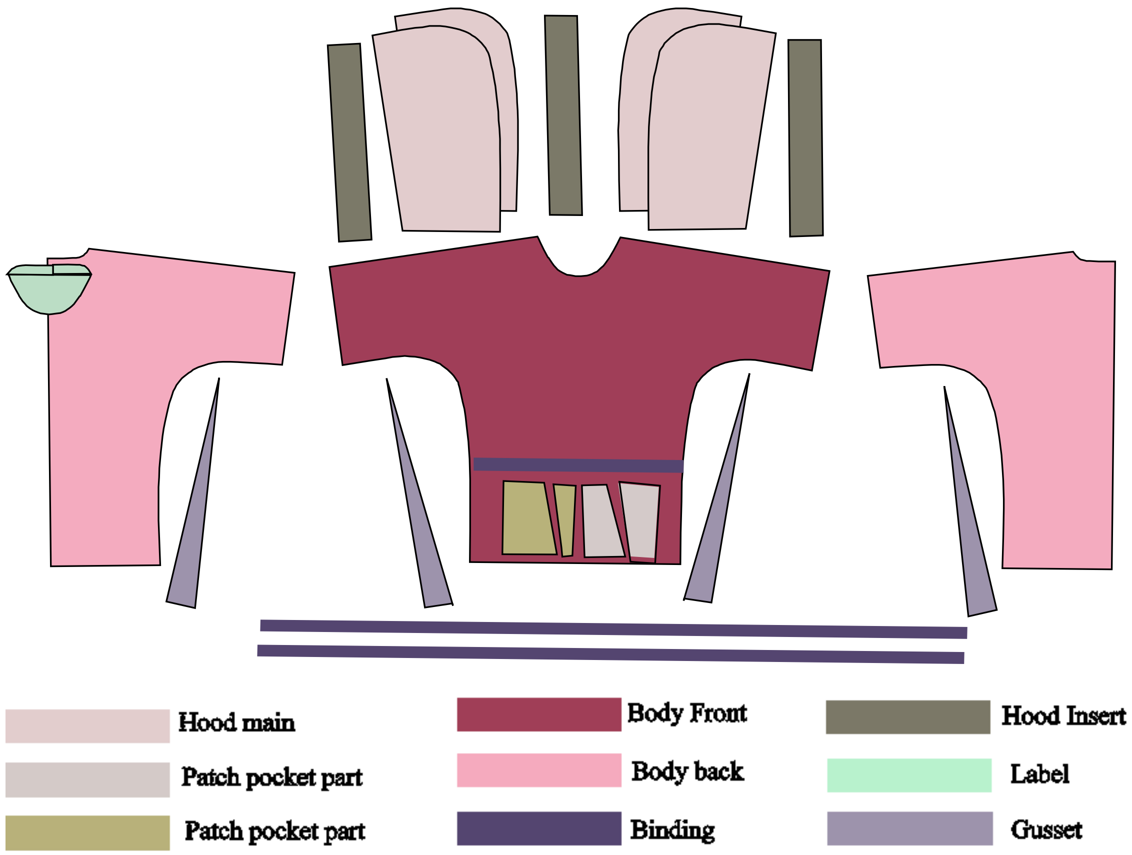


Figure 4: technical design of the Hooded t-shirt

Figure **5**: a) Silhouette of traditional patterns for t-shirt (Aldrich, 2011), b) silhouette of the chosen design, c) marker planning in the PDS widow, d) Coloured illustrations of all pattern pieces.

2.2.2 Marker making and cut order plan

Once satisfactory pattern designs for both selected styles are developed in the PDS window as shown in the figures 3c and 5c, they are transferred to the GEO app to finalise the cut order plan (i.e. the marker) for all sizes and calculate the fabric utilisation, which is presented in the section 3.1.

2.2.3 Prototyping and wearer trial

A prototype garment in size M was made for each style for the fit evaluation. Table 3 presents the fabrics used and table 4 illustrates the construction methods used to assemble the prototype garments.

Table 3: List of fabrics used for making prototypes

Garment	Fabric name	Composition	Construction	Weight
Joggers	Single jersey	Cotton elastane	Knit	180 gsm
Hooded t-shirt	2x2 rib jersey	Cotton elastane	Knit	200 gsm

Table 4: The construction methods used to assemble the sample garments

Garment	Garment area	Assembly method (stitch class)
Sweatpants	Pockets insertion	Lockstitch 301
	Body Seams	4 thread overlock 514
	Waistband attachment	Lockstitch 301
	Legs cuffs	4 thread overlock 514
Hooded T-shirts	Body Seams	4 thread overlock 514
	Hood seams	4 thread overlock 514 and Lockstitch 301
	Hood attachment	Lockstitch 301
	Cuffs	4 thread overlock 514
	Hem	4 thread overlock 514 and Lockstitch 301

Lockstitch 301 does not price any fabric waste as it forms simple superimposed seam. Traditionally overlock 514 stich class produces a fabric trim off to produce a neat seam as it is mentioned in the section 2.1. However, for this work machine setting was adjusted in such a way that no fabric trim-off is produced.

All prototypes are tried on a live model having the body measurements presented in the table 5 and the fit of clothing was assessed visually using the five good clues to fit (Erwin and Kinchen, 1969), which are:

- Grain: Ensuring the fabric is cut on the correct direction of the fabric
- Set: Wrinkle free garment that fits smoothly
- Line: Good construction of seams and garment edges
- Balance: Good hang on the body, from both front and back view
- Ease: Reasonable looseness of garment in relation to size and design.

Table 5: Body measurements of chosen models

Point of measure	Body measurements (cm) *(measured as per BS ISO 8559-1, 2017)*
Chest	90
Waist	78
Lower Hips	100
Upper Hips	95
Biceps	28
Elbows	25
Wrist	16
Shoulders	16
Arms	62
Neck	43
Head	60
Height	186
Inner Leg	80
Thigh	50
knees	39
Calf	36
Ankle	24.5

3. Results

3.1 Fabric utilisation

Figures 6 and 7 illustrate the ZW marker lay plans of the styles in three sizes each. It is remarkable that over 98% of utilisation of fabric was achieved for both styles, while in traditional industrial practice over 85% is considered impossible (Carrico and Kim, 2014). The fabric lay-plan of joggers gave a utilisation of 98.35% of fabrics as the geometry of the pattern shapes were carefully considered in addition to the ZWPC technique and inverse negative space concept applied carefully. For the hooded t-shirt, the achieved fabric utilisation was 98.51% due to careful implementation of jigsaw method and inverse negative space concept for maximum fabric usage.

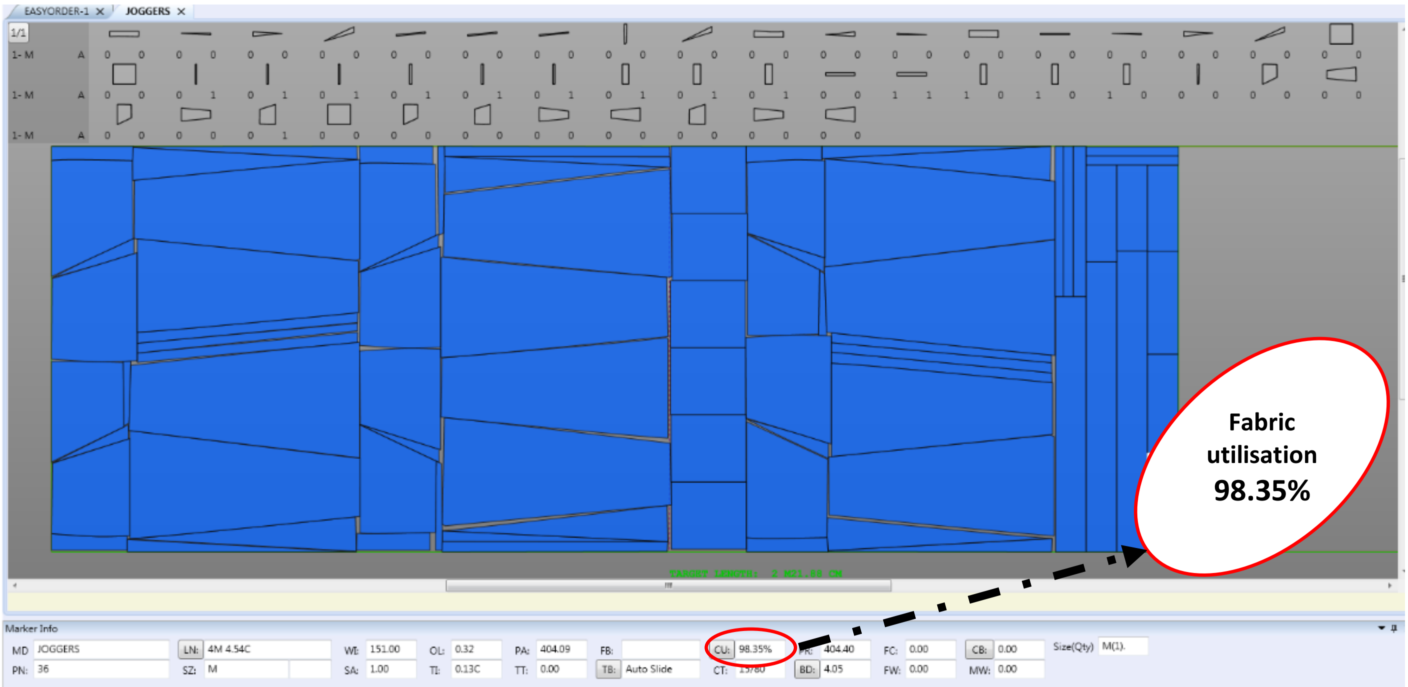


Figure 6: Lay plan of sweatpants with 98.35% fabric utilisation

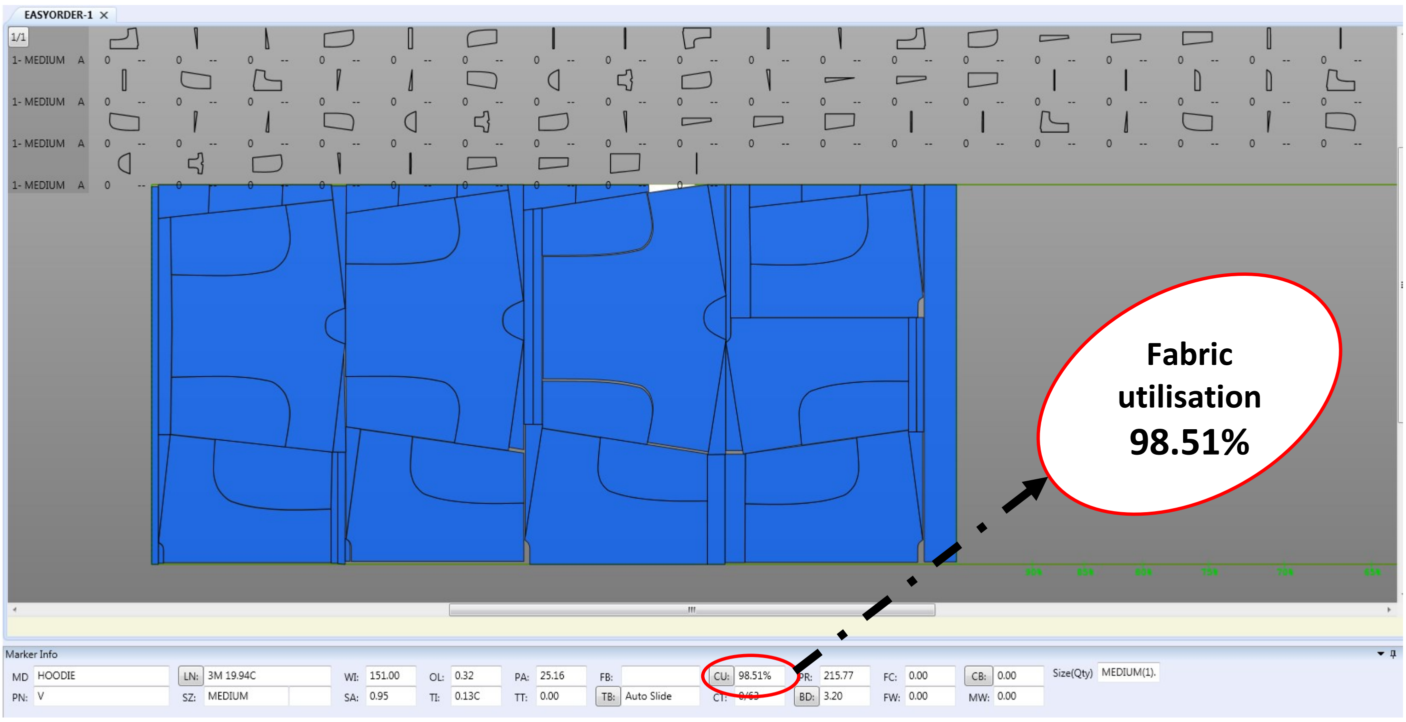


Figure 7: Lay plan of hooded t-shirts with 98.51% fabric utilisation

3.2 Fit assessment

The fit of both prototypes was assessed through a fitting session with a model of matching size (see Figures 8). When assessed against five good clues of fit – grain, set, line, balance and ease, as mentioned in the section 2.2.3, both prototypes are found to have an acceptable level of fit, while the workmanship related to 'set' could be further improved with higher skill in assembling. The hooded t-shirt appeared to have a few wrinkles on front at side chest areas, however these are not unusual in garments made of knitted fabrics.

Figure 8: Wearer Trials of the prototypes of a) Hooded t-shirt (size M), b) Sweatpants (Size M)

4. Discussion

4.1 Framework for implementing ZWPC in mass production

It is evident from the results mentioned in the section 3 that the strategic framework presented in the figure 1 is effective in implementing ZWPC for production of multiple sizes and in other words in mass production of apparel. The markers presented in the figures 6 and 7 are made for three different sizes of the chosen styles. However, the whole technique will work effectively for any number of sizes that are multiples of three.

Figure 9 illustrates the factors need to be considered while implementing ZWPC for mass production of apparel. All these factors should be considered simultaneously and in a synchronised manner. This comprehensive thinking process is the philosophical backbone of the ZWPC concept and is key to its success. This work gives birth to two key pathways to implement ZWPC in mass production of apparel, which were not discussed before. They are the "multiple size approach" and the "inverse negative space approach" for thinking and implementing ZWPC.

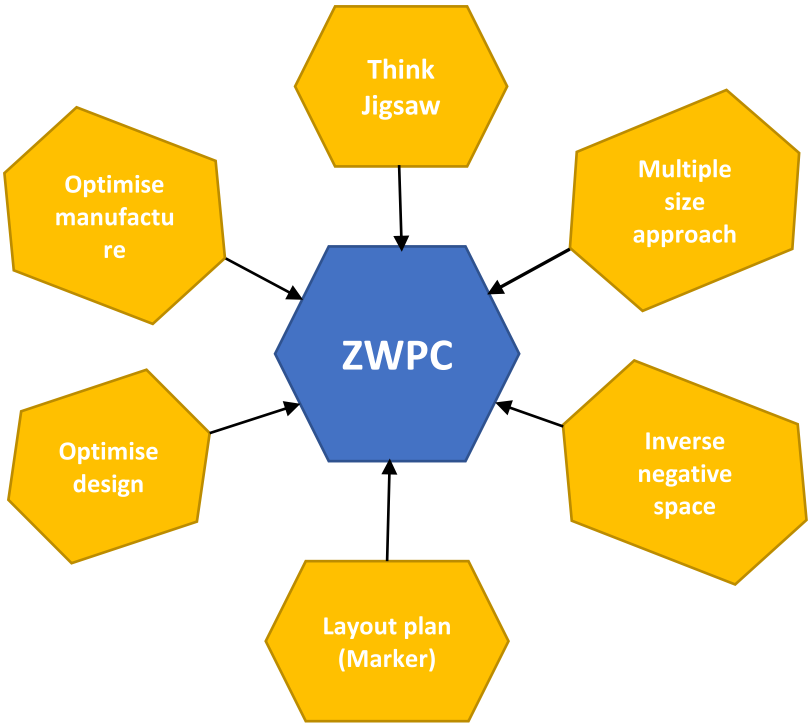
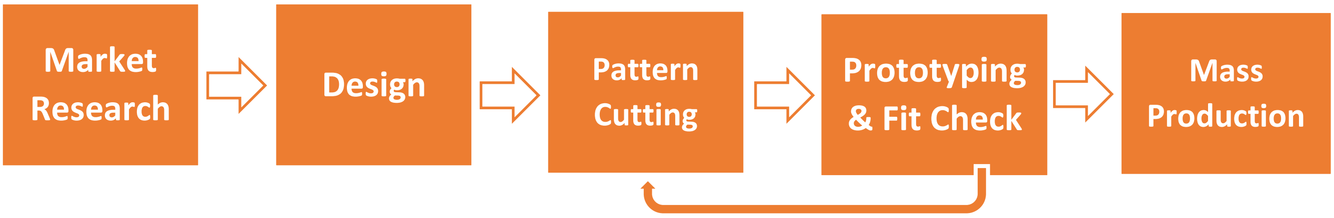


Figure **9**: ZWPC Paradigm

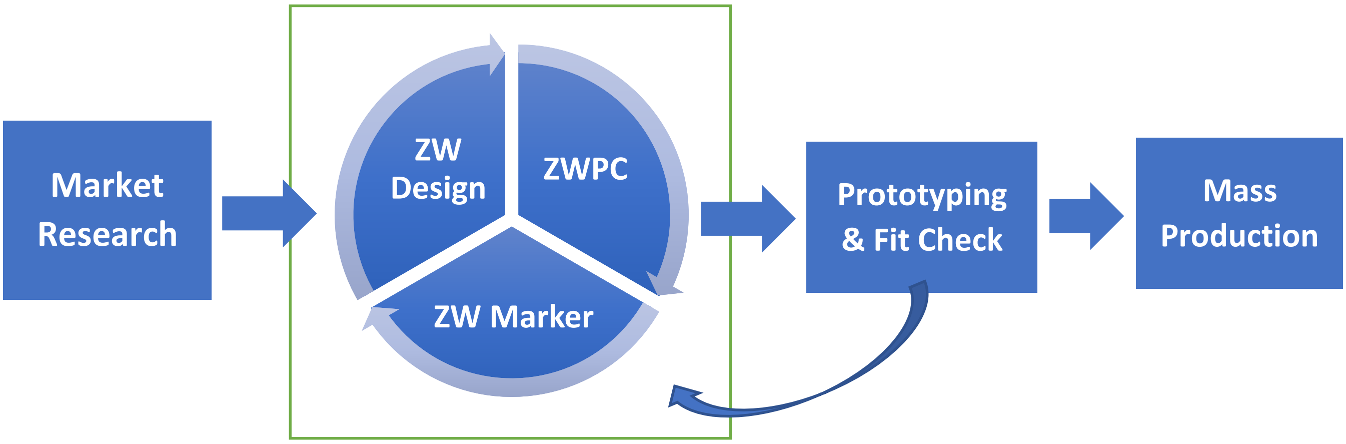
It is found that the size of the negative spaces forms in inverse proportion to the size of the patterns. Hence, the negative space from smaller sizes are used to create details for the bigger sizes (see figures 3c,d and 5c,d). For example, the negative space created from a size L is small enough to create a pocket for a main body of size S and vice-versa. This concept can be applied in large scale in the fashion industry.

The use of gathers and an elastic waistband has been found as an excellent way to attain the right fit for each size to control unwanted fullness. For a garment to be truly ZW, all aspects of assembly process must be taken into consideration, for example and the stitching of seams and hems. While overlocking is a common way of joining seams in sportswear and casual wear, it usually creates a trim-off of 2-4 mm, which contributes to fabric wastage. In this work, all seams are joined by overlocking with a machine setting of 5 mm seam allowance so that no trim-off would be created. This makes the garments to be truly ZW. However, this demands a high level of skill from machinists for operating a 4-thread over-locker. Another successful ZW finishing method used in work was the use of binding in several areas. Bindings can be made from the unused fabric in the lay-plan and did not require trim-offs while assembling the garments.

To implement ZWPC, the acts of apparel design, pattern cutting, grading and marker making are done simultaneously as a single step throughout this work. For this to happen, it is crucial that a single person or a single team design and cut patterns simultaneously as decisions concerning style lines and pattern pieces are to be made in a synchronised way. Decisions on how to devise the lay-plan and how to use the negative space on the fabric, and generation of garment design ideas are sketched at the same time, because it is important for designer to visualise the finished garment as the pattern pieces are being shaped. For example, it was both a design and pattern making decision to use the negative space underneath the armhole side seam of the t-shirt to construct a hood out of that. Similarly, it was both a functional and aesthetic design and pattern making decision to construct gussets out of negative space. Both pattern making and design skills are crucial to make a functional yet aesthetically pleasing garment. The conventional design process in the fashion industry as mentioned in the section 1, is split into different stages with little communication between the professionals involved in each stage (see Figure 10a). This make the implementation of ZWPC in mass production impossible unless a new design process is adopted. Figure 10b proposes a design process for applying ZWPC in mass production.



a) Conventional Apparel Design Process



b) Proposed ZW Apparel Design Process

Figure 10: Conventional vs Proposed Apparel Design Process

The steps of the design process should not jump from one to another without impacting on each other, rather it should be a simultaneous process in which they interact with each other until the desired prototype is achieved. This ideal process calls for a hybrid role combining design and pattern cutting (as mentioned in the section 2.1) so that sustainable, efficient, functional as well as aesthetically pleasing and trendy designs can be produced.

4.2 Addressing the Barriers

Based on the information extracted from literature (James et al., 2016; Mcquillan, 2011; Towsend & Mills, 2013; Niinimaki, 2013; Carrico and Kim, 2014; Rissanen and Mcquillan, 2016) and the experience gained from this work, this section discusses the barriers to implement ZWPC in mass production and how those can be addressed.

4.2.1 Filling communication gap

The first step to implement ZWPC, as mentioned earlier, would be to close the communication gap between designers and pattern makers in the fashion industry. This can easily be done by setting up a hybrid fashion designer – patter cutter role, in which a single person will do the tasks of designing and pattern cutting following the factors presented in the figures 9 and 10b and demonstrated in the sections 2 and 3. Alternatively a team can be set up including both designers and patter cutters who will work hand in hand right from the beginning stage and will combine pattern cutting with fashion design. This could be an area of interest for fashion companies that focus on sustainability and environmental concerns in their production strategy and marketing campaigns.

4.2.2 Demystifying the myth of high time consumption

At first look, the time requirement to develop ZW patterns could seem to be high, but, it is not. The time consumed in ZWPC is the total of combined time requirements for the processes of design, pattern cut and prototyping, which are traditionally done separately. When the time consumptions for all these traditional processes done in isolation are added up, it will be even higher than the time required for a ZWPC of a same style. Moreover, ZW patterns for basic styles that do not go out of trend, like those developed in this work, could be designed and used over and over, again and again for different seasons and years. Those styles could be produced in different colourways and prints every year or even can be slightly tweaked to meet trends and consume demands.

4.2.3 Digital pattern cutting

Another hurdle in embracing ZWPC might be that some designers may not have skill of and access to digital pattern cutting tools. Using digital pattern cutting throughout this experiment has been found as a time-saving, accurate and efficient way of working on ZWPC; otherwise it may have been impossible to achieve the same result using manual flat pattern cutting in a similar time scale. Fashion design and technology courses offered at different universities include digital pattern cutting training for students, however their curricula should also include ZWPC.

4.2.4 Scrapping the thought-terminating clichés

Another concern in mass-producing ZW fashion is to ensure all styles are visually similar to conventional non-ZW designs. ZW designs may often end up looking too crafty as demonstrated in Mcquillan (2011), Towsend & Mills (2013), Niinimaki (2013), Carrico and Kim, (2014), Rissanen and Mcquillan (2016). Designing ZW styles that are aesthetically similar to conventional fashion and equally appealing and marketable is a challenge for the designers. In this work, the garments were designed to appear as comparable as possible to traditional high street garments. The styles only had a reasonable number of decorative features that include features like raglan sleeves, patch pockets and hood, which are also common features in high-street fashion.

5.0 Conclusion

The primary aim of this research was to test the application of ZWPC for multiple sizes of same style to develop a pathway for implementing this approach in mass production of apparel. Taking this into consideration that a mini high-street collection of styles was designed in three different sizes of each and both styles achieved above 98% of fabric utilisation. This confirms that ZWPC can indeed be implemented in mass production and this work has, for the first time, demonstrated this. As it worked for the combination of three sizes, it can be assumed that it will also work for any combination of sizes that is multiple of three. The notable outcomes of this work are the development of a strategic framework and the ZWPC paradigm. Devising and testing of the concepts of “multiple size approach” and “inverse negative space” for ZWPC also mark the originality of this work. Another positive result from the research was the successful achievement of the commercial appeal to the styles, while ensuring that the garment did not look too different from conventional non-ZW garments.

The barriers to incorporating ZWPC in mass production are the lack of collaboration between designers and pattern makers, skill requirement for digital pattern cutting, and failure to meet mainstream designs. This work has addressed these issues by proposing and demonstrating a new apparel design process, where design and pattern making is a singular process to be undertaken by one person or a team taking a hybrid role.

To conclude, ZWPC in mass production is not impossible, but it would call for an alternative design process to be managed by hybrid designers-pattern cutters. It would also call for high-street brands willing to recruit people with such skills and willing to invest in digital pattern cutting software. A shift into ZW garments could be a ground-breaking way of reducing excessive burden of waste fabric onto landfills, and it is completely achievable as it has been demonstrated in this work. This provides a potential solution to reduce an estimated amount about 60 billion square metres or more of scarp fabrics, that produce industrial carbon footprint ranging between 21.9 and 337.7 billion kg of CO_2 equivalent, caused by being produced by the fashion industry.

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