FIBRES & TEXTILES in Eastern Europe
sciendo
FIBRES & TEXTILES in Eastern Europe

Research Article • DOI: 10.2478/ftee-2023-0029 FTEE • 31(3) • 2023 • 64–73

Flexible Design of Garment Styles to Support the Minimal Waste Concept in the Fashion Industry

Ineta Vilumsone-Nemes[1]*, Marija Pešić[1], Edit Csanák[2]

[1] *University of Novi Sad, Technical Faculty "Mihajlo Pupin", Department of Basic and Applied sciences, Serbia*
[2] *Óbuda University, Rejtő Sándor Faculty of Light Industry and Environmental Engineering, Product Design Institute, Hungary*
* *Corresponding author. E-mail: inetavil@gmail.com*

Abstract
Currently, the design of garment styles is weakly supporting the MWD concept. It is kept fixed during all its very changeable manufacturing process, thereby increasing pre- and post-consumer fabric wastes. To improve the situation the final values of construction parameters which influence fabric use efficiency should be determined for every unique production order only in the garment manufacturing process. Four garment styles were tested to see how light changes in their width and length influence fabric use efficiency. Even minimal reduction of these parameters can give noticeable fabric savings. Different values of these parameters create slightly different shapes of pattern pieces, and with it, give a huge number of new possibilities to create more efficient production markers. The authors found a way how to make the garment designing process more efficient, as well as, to create a "virtual bridge" between garment designing and the manufacturing phase. Both improvements could give serious benefits: reduced fabric use and product price, as well as, reduced pre- and post-consumer textile material wastes.

Keywords
garment designing, minimal waste design, textile waste, environmental problems, fabric use efficiency, product costs.

1. Introduction

The market is currently dominated by the fast fashion business model. Fashion trends, and with it their demands, are changing very rapidly and the industry offers a huge number of goods available for low prices [1, 2, 3]. The fashion brands are producing almost twice the amount of clothing compared with the time before the year 2000. Serious competition in the market and much less time available for well-considered planning and designing [4] have pushed apparel companies to produce garments which conform to lower quality standards than 20 years ago [5]. However, it does not create noticeable problems for modern customers. While consumers are buying more, they wear the purchased items less - the average garment-use time has decreased by 36% compared with 2005 [6]. Garments have become more entertainment than functional products [3] - their visual attractiveness is much more important than the perfect design and correct technologies used to manufacture them.

Here it has to be added that in the traditional two collection per year system, used in the mass production of clothing, the quality standards were higher [3], but the design of a garment style has never been perfect because of several objective reasons. Garments are produced using standardized size systems [7] and huge number of individuals simply do not fit perfectly to those standardized sizes [8]. The same garment style is manufactured in different sizes, however in the pattern grading process, the design of a garment style is not perfectly conformed to every separate size [9]. Finally, most often a single garment does not make an outfit. Customers by themselves create their own sets from separately obtained garments, not always getting perfect design solutions.

It is clearly seen that, comparing with other industries where products are manufactured in a single size and for a very clear use, garment styles cannot be designed perfectly. But, if this is so, why is the design of agarment style so carefully kept fixed during all its manufacturing period, often sacrificing two important factors - efficient use of fabric and its waste?

2. Zero and minimal waste design concepts in the fashion industry

Textile waste used to be divided in two groups: pre-consumer and post-consumer waste. In the garment production process, pre-consumer waste is obtained from leftover raw materials: off cuts, selvages, roll ends, and rejected materials [4, 10]. The amount of this waste (15-25% of fabric used) is dependent on marker efficiency in the garment component cutting process. Studies show that it is influenced by many variables, including garment type and design [11, 12].

Post-consumer waste is worn out, damaged and unwanted clothing. In the fast fashion business model, this part of waste contains short term used unwanted clothing and also ready garments which have not been sold [13]. The amount of this waste depends on customers' behaviour in the market. However, it is also influenced by garment manufacturers who can and have to offer garment styles with maximally minimal raw material use - the less raw material used to create a certain design idea, the less textile waste obtained at the end of the lifetime of a product.

In the fashion industry two concepts support the textile waste reduction idea in the product designing phase - zero waste design (ZWD) and minimal waste design (MWD). ZWD refers to the practice of designing garment styles so that the components arranged on a piece of fabric do not create any material waste (or this waste is used to create other products or is recycled) [14, 15]. MWD is apparel designing and development process which uses different methods to reduce material waste to a minimum [16, 17, 18].

3. Historical development of ZWD and MWD concepts

Zero-waste and the philosophy behind it dates back to traditional garments. The national clothing of many countries, such as Egypt, Greece, Rome, India, Japan and Korea are good examples of zero waste design [19, 20]. Linen, cotton or hem shirts or trousers created from rectangle pieces of fabric are a part of the national costumes of many nations. Pre-industrial societies treated fabric as a precious resource. Differences between ready goods showing the social status of their owners were obtained using different weaving, dying and embroidery techniques, as well as decorating and draping fabrics [21, 22].

The value of textile materials changed with the first and following industrial revolutions, when the fabric manufacturing process became faster, easier, and cheaper [23]. Then fashionable garment styles with larger material consumption and certain raw material waste became affordable not only to rich people but also to the middle class population [24, 25]. The introduction of manmade fibers in the19th century and industrial fabric manufacturing made textile goods affordable to everybody [26, 27]. Clothing designers and manufacturers became entirely comfortable creating garments in accordance with constantly changing fashion trends.

However, with the protests against traditional life and fashion standards from the 1960s to 1980s, the subcultures of hippies, punks and goths created their own second-hand fashion, giving new value to already used garments. For the first time fashion designers, such as Martin Margiela, Issey Miyake, Rei Kawakubo and Yohji Yamamoto, started to use Zero-waste design concepts in their fashion collections [28].

At the industry level efficient material use and raw material waste problems appeared again only in the second half of the 20th century, when input costs of textile and garment manufacturers - labour, energy, and raw materials - started to grow seriously [23, 29]. Then the first CAD/CAM systems for garment designing, pattern making, fabric spreading and cutting were introduced to increase work efficiency and productivity, as well as, to reduce material consumption [30, 31]. At the beginning of the 21st century, cut planning software was introduced. It helped to organize the work processes in a cutting room and minimize raw material losses [32].

Currently, the minimal waste design (MWD) concept has become actual in the apparel industry. It helps to solve economical problems - to reduce product costs, fabric consumption and pre-customer material waste. During the last decade, the fast fashion phenomenon has widened the aims of the minimal waste design (MWD) concept, adding also the necessity to reduce pre- and post-consumer textile waste and with it environmental problems [11, 20, 33, 34, 35].

4. Existing limitations and research challenges in implementing MWD in the fashion industry

In the fashion industry the aims of MWD are very challenging. The main factors which create fabric waste are as follows:

- specific qualities of textile materials - different qualities of the material in the direction of warp and weft, fabric pattern, pile, selvages, and others [36],
- complicated and fixed shapes of garment components,
- highly variable product manufacturing process.

The losses of the first group are determined by current technologies used in the textile manufacturing process. They will be reduced or even avoided using advanced fabric and garment manufacturing principles and methods (for example, using 3D printing) [37]. The second part of the fabric waste factors is directly connected with the efficiency of the MWD concept used in developing a garment style - the shapes of its components and possibility to match their outline in a 2D rectangle fabric piece [12, 38]. To reduce this part of material waste, the fashion industry should accept simplified shape garments while offering attractive designs to its customers using different colours, printings, and surface decorations. Textiles have to be treated as a “precious resource” again, not only because of their increasing prices but also because of serious environmental problems which derive from post-consumer textile wastes. “Customers must understand fashion as more of a functional product rather than entertainment, and be ready to pay higher prices that account for the environmental impact of fashion” Scandinavian researchers conclude in their paper “*The environmental price of fast fashion”*[10].

Besides the two challenges already mentioned, there is one more - the efficiency of textile material use depends on many parameters of the garment manufacturing process, such as, ordered quantities, sizes, materials, colours, the combination of sizes in markers, specifics of a cutting area, equipment used, and others, which are not known in the product designing phase [39]. It means that the fixed product design cannot ensure efficient material use, which is one of the serious causes of increased pre and post-consumer textile wastes in the fashion industry. To reduce or eliminate this problem, the design of a garment style has to be made flexible to react efficiently and promptly to different changes in the further product manufacturing process.

5. Experiments

Two experiments were performed to find new ways to support the MWD (minimal waste design) concept in the garment manufacturing process. An initial sample of a bell skirt was freely created. Four other styles were taken from garment collections which had been manufactured in real mass productions conditions.

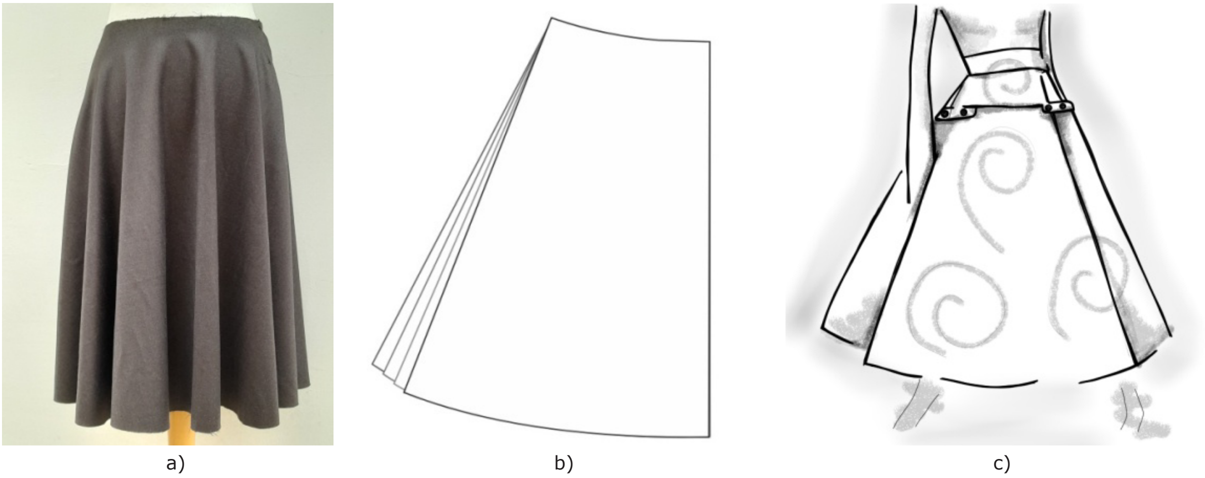

Fig. 1. a) Simplified samples of a bell skirt tested, b) the principle of the widening reduction, and c)a bell skirt A

5.1. First experiment

To explore possibilities of creating a single design idea with separate flexible construction parameters, it was decided to create simplified samples of a bell skirt (***Figure 1.a***) using different levels of its *widening*. Five samples were made from the same textile material changing their widening (bottom line perimeter) at intervals of 2 cm (***Figure 1.b***). The ready skirts were visually compared. There was no visual difference noted and hence no difference in the design concept between the three skirts with widenings of 7 cm, 9 cm and 11 cm. A noticeable visual difference appeared between the first skirt, with a widening of 7 cm, and the fifth skirt, with a widening of 15 cm. However, the original design concept did not change - both the first and fifth skirts maintained the construction solution and visual appearance of a bell skirt.

The experiment was continued with a similar bell skirt design A, which was fully developed for mass productions conditions (***Figure 1.c***), to see the influence of the slightly different widening of the skirt on fabric use efficiency.

Three groups of markers for sizes 38-50 were created:

- *1st group* - markers combining two skirts of different sizes with their original widening;
- *2nd group* - markers combining two skirts of different sizes while reducing their widening by 4 cm (reducing the total bottom line perimeter by 4 cm) and 8 cm - amounts which should not influence the original design idea of the skirt;
- *3rd group* - markers combining two skirts of different sizes with different widening levels - for example, a skirt of size 38 with the original widening and a skirt of size 48 with a 4 cm reduced widening, and vice versa.

Markers were created for the different size combinations as would be done for the real manufacturing process:

- combining the smallest sizes with the largest ones (in a standard way to get the best marker efficiency): 36/50, 38/48, 40/46, 42/44,
- creating other combinations of sizes which could appear making a *cut plan* for real manufacturing orders with different ordered quantities for every size (24 markers with all other possible two size combinations).

5.1.1. Markers of skirt couples with the same widening level

A total 84 markers were created for the skirt with the original widening (1st group) and the one with the 4 cm and 8 cm reduced widening (2nd group). The marker length and efficiency of the markers developed are seen in ***Table 1*** and ***2*** in *widening* rows: *org*, *-4* and *-8* (because of large number of data, only more often used size combinations are shown in the tables).

Comparing same size couple markers of the 1st group (original widening) and 2nd group, it was seen that the 4 cm widening reduction resulted in 1.27-2.76 % reduced fabric consumption and up to 0.41 % increased marker efficiency (***Figure 2***).

By reducing the skirt widening by 8 cm, fabric savings were even larger - fabric consumption was reduced by 2.04-2.92 % but the marker efficiency increased up to 0.52 %, (***Figure 2***). However, it was found that in 3 markers the marker efficiency did not increase - it decreased slightly. For example, for a size couple 42/44 with 4 cm reduced widening, the marker efficiency decreased by 0.132 % (see ***Table 2***, row: *widening*, *-4*). Obviously, the skirts of reduced widening ensured lower fabric consumption; however, the area of the fabric was filled in a less efficient way than for skirts of the original widening.

5.1.2. Markers for skirt couples of different widening levels

As the experiment with the simplified bell skirt (***Figure 1.a***) proved that this kind of skirt can keep the same visual perception and design idea with more than one slightly different widening level, a third group of markers were created. This time two *skirts with different widening levels* in their tolerance intervals were *combined in a marker*. In the third group 56 markers were tested for all previously mentioned size combinations using in a couple a smaller size skirt with the original

Parameter	Value		Marker length (cm)			
	Style	cm	Size: 42/44	Size: 40/46	Size: 38/48	Size: 36/50
Widening	**A**	**org**	208,17	207,64	204,54	207,94
	A	**-8**	203,78	201,66	199,51	202,82
Changes:		↓	**-4.39cm -2.10%**	**-5.98cm -2.88%**	**-4.97cm -2.46%**	**-5.12cm -2.46%**
		-4	204,19	204,77	198,89	203.13
Changes		↓	**-3,98cm -1,91%**	**-2,87cm -1,38%**	**-5,65cm -2,76%**	**-4,81cm -2,31%**
		org/-4	204,67	205,34	202,87	204,12
Changes:		↓	**-3,50cm -1,68%**	**-2,30cm -1,1%**	**1,67cm -0,82**	**-3,82cn -1,84**
		-4/org	205,89	206,02	201,34	205,31
Changes:		↓	**-2,28cm -1,09%**	**-1,62cm -0,78%**	**-3,2cm -1,56%**	**-2,63cm -1,26%**
Lenght	**A**	**org**	208,17	207,64	204,54	207,94
	A	**-2**	197,90	199,18	197,67	199,13
Changes:		↓	**-10.27cm -4.93%**	**8.46cm -4.07%**	**6.87cm -3.36%**	**-8.81cm -4.24%**

Table 1. Changes of marker length (fabric consumption)

Parameter	Value		Marker efficiency (%)			
	Style	cm	Size: 42/44	Size: 40/46	Size: 38/48	36/50
Widening	**A**	**org**	83,505	83,336	83,260	82,662
	A	**-8**	83,703	83,786	83,372	82,792
Changes:		↑	**+0,198%**	**+0.450%**	**+0.112%**	**+0.130%**
		-4	83,373	83,709	83,470	82,897
Changes:		↑	**-0.132%**	**+0.373%**	**+0.210%**	**+0.235%**
		org/-4	83,761	83,638	83,736	83,048
Changes:		↑	**+0,256%**	**+0,302%**	**+0,476%**	**+0.386%**
		-4/org	83,608	83,249	83,543	82,896
Changes:		↑	**+0,103%**	**-0,087%**	**+0,283%**	**+0.234%**
Length	**A**	**org**	83,505	83,336	83,260	82,662
	A	**-2**	84,575	83,634	82,902	83,073
Changes:		↑	**+1.070%**	**+0.298%**	**+0.358%**	**+0.411%**

Table 2. Changes of marker efficiency (fabric use efficiency)

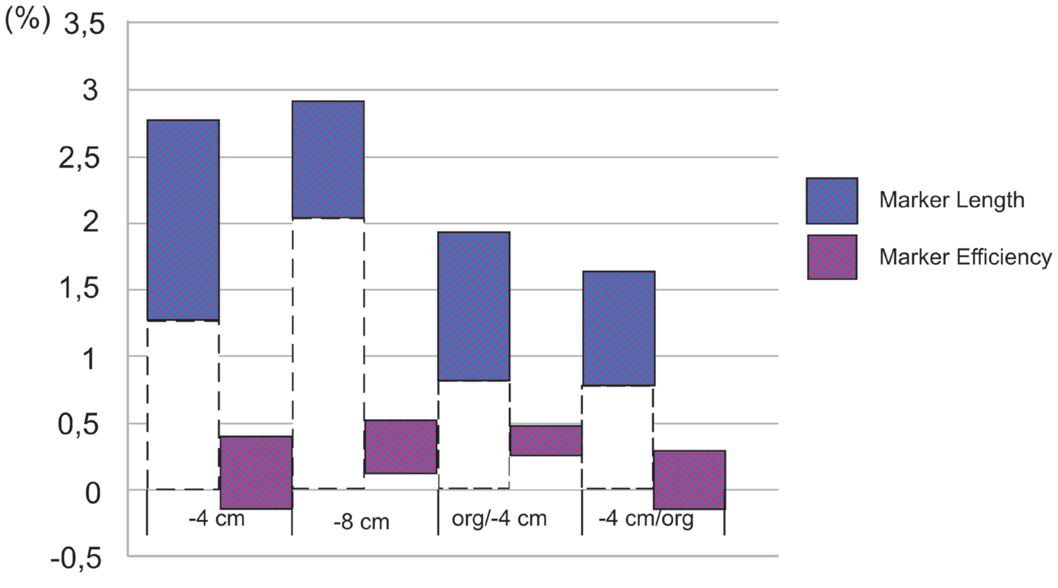

Fig. 2. Intervals of marker length and efficiency improvements

Fig. 3. a) dress B, b) blouse C, and c) blazer D.

widening and a larger size skirt with a 4 cm reduced widening, and vice versa (for more often used size combinations see ***Table 1*** and ***Table 2***, *widening* rows: *org/-4* and *-4/org*).

Then, fabric use efficiency was compared between the same size couple markers of the first group of skirts with the original widening, and the third group - one skirt with the original widening, and another one with 4 cm reduced widening. Comparison showed that the reduction of widening for one of the skirts in the couple always gave reduced fabric consumption comparing with the markers with the original widening for both skirts. The fabric consumptions decreased in the interval 0.78-1.94 %(***Figure 2***). A different situation appeared with the marker efficiency. It changed from -0.071 % up to +0.476 % (***Figure 2***). Three markers of skirts with different widening levels in the couple (third group) had a slightly lower marker efficiency than the same size couple markers of skirts with the original widening (first group). However, in the same third group, 7 markers were found with the highest marker efficiency comparing with the markers of skirts with the original widening and 4 cm reduced widening. Comparison showed that for some size combinations, markers with skirts of slightly different widening level can give better marker efficiency than a marker of two skirts with the same widening level.

5.1.3. Markers for skirt couples with reduced length

It was decided to check how the fabric consumptions and marker efficiency can be influenced changing also the length of bell skirt A. To keep the original design concept, its length was reduced by 2 cm. New markers were created for same size couples. A slight reduction of the length resulted in 3.04-4.93 % reduced fabric consumption and up to 1.07 % increased marker efficiency (for more often used size combinations see ***Table 1*** and ***Table 2***).

5.2. Second experiment

To see how fabric use efficiency can be affected by changing the widening or length of other garment styles, three more styles: dress B, blouse C and blazer D (***Figure3***) were tested. The markers were created for more often used size combinations in the interval 36-50.

Reduction of widening: The widening was reduced for dress B and blouse C (***Figure 3.a,b***). The reduction of the bottom widening of dress B (- 8cm) resulted in 0.33-1.36 % increased marker efficiency and 2.49-4.83 % reduced fabric consumption. Similarly, the reduction of the sleeve bottom widening of blouse C (-2cm) resulted in 0.57-1.92 % increased marker efficiency and 1.91-3.47 % reduced fabric consumption (***Table 3*** and ***Table 4***).

Reductions of length: The length was slightly reduced for dress B and blazer D (***Figure 3.a,c***). The length was reduced slightly to keep the original design concept: 3 cm for dress B and 2 cm for blazer D. The reduction of the length of dress B (-3 cm) resulted in 0.04-0.88 % increased marker efficiency and 3.59-4.72 % reduced fabric consumption. The reduction of the length of blazer D (-2 cm) resulted in 0.07-1.18 % increased marker efficiency and 1.11-3.50 % reduced fabric consumption (***Table 3*** and ***Table 4***).

Reduction of widening and length: As for dress B (***Figure 3.a***) reduction of its widening (-8 cm) gave the largest fabric savings, it was decided to reduce slightly both - its widening (-8 cm) and also the length (-3 cm). Results showed that the slight reduction of two construction parameters gave noticeable fabric savings. Fabric use efficiency increased by1.41-2.39 %. Fabric consumption decreased by 6.11-7.34 %, saving 33-40 cm fabric for the marker (***Table 3*** and ***Table 4***).

6. Discussions and results

It is well known that marker length and efficiency is influenced by two factors –the shapes of pattern pieces and their mutual placement. Currently, the industry is using different software to find the most efficient mutual placement of pattern pieces on the fabric. There is software available which can generate and screen

Parameter	**Value**		**Marker length (cm)**			
	Style	**cm**	**Size: 42-44**	**Size: 40-46**	**Size: 38-48**	**Size: 36-50**
Widening	**B**	org	536,45	536,19	541,83	546,42
	B	**-8**	515,64	522,85	515,64	531,76
Changes:		↓	**-20.81cm -3.88%**	**-13.34cm -2.49%**	**-26.19cm -4.83%**	**-14.66cm -2.68%**
	C	org	214,33	216,93	218,76	221,70
	C	**-2**	210,23	209,40	213,46	215,91
Changes:		↓	**-4,10cm -1.91%**	**-7.53cm -3.47%**	**-5.30cm -2.42%**	**-5.79cm -2.61%**
Length	**B**	org	536,45	536,19	541,83	546,42
	B	**-3**	511,12	516,91	521,19	524,56
Changes:		↓	**-25.33cm -4.72%**	**-19.28cm -3.59%**	**-20.64cm -3.81%**	**-21.86cm -4.00%**
	D	org	331,98	332,97	336,30	336,25
	D	**-2**	320,36	324,90	327,31	332,51
Changes:		↓	**-11.62cm -3.50%**	**-8.07cm -2.42%**	**-8.99cm -2.67%**	**-3.74cm -1.11%**
Widening	**B**	org	536,45	536,19	541,83	546,42
and length	**B**	**-8/-3**	499,22	503,42	502,04	509,78
Changes:		↓	**-37.23cm -6.94%**	**-32.77cm -6.11%**	**-39.79cm -7.34%**	**-36.64cm -6.70%**

Table 3. Changes of marker length (fabric consumption)

Parameter	**Value**		**Marker efficiency (%)**			
	Style	**cm**	**Size: 42-44**	**Size: 40-46**	**Size: 38-48**	**36,50**
Widening	**B**	org	71,588	71,980	71,595	71,369
	B	**-8**	72,948	72,308	72,947	71,850
Changes:		↑	**+1.360%**	**+0.328%**	**+1.352%**	**+0.481%**
	C	org	83,140	82,905	82,996	82,697
	C	**-2**	83,707	84,827	84,016	83,885
Changes:		↑	**+0.567%**	**+1.922%**	**+1.020%**	**+1.188%**
Length	**B**	org	71,588	71,980	71,595	71,369
	B	**-3**	72,469	72,021	71,803	71,726
Changes:		↑	**+0.881%**	**+0.041%**	**+0.208%**	**+0.357%**
	D	org	78,910%	79,194	78,944	79,508
	D	**-2**	79,654	79,061	79,015	78,325
Changes:		↑	**+0.744%**	**+0.133%**	**+0.071%**	**+1.183%**
Widening	**B**	org	71,588	71,980	71,595	71,369
and length	**B**	**-8/-3**	73,629	73,390	73,981	73,253
Changes:		↑	**+2.041%**	**+1.41%**	**+2.386%**	**+1.884%**

Table 4. Changes of fabric marker efficiency (fabric use efficiency)

an unlimited number of markers in a few seconds to find the most efficient ones for every manufacturing order [12, 32]. Till now there have been no methods created to influence fabric use efficiency with the second important factor –the shapes of pattern pieces.

However, the experiment with the bell skirt showed that the original design idea can be kept unchanged using slightly different values of certain construction parameters, for example, widening and length. But, when changing the values of any construction parameter, the shapes of pattern pieces change too, and with it, new possibilities to place pattern pieces in the markers appear. Flexible construction parameters give the possibility to develop a huge number of new pattern pieces for single garment styles and, hence, to improve fabric use efficiency with the *shapes of pattern pieces*.

Obviously, the values of these construction parameters (length, widening, width, others) can be used at certain tolerance intervals in which the visual perception of the style does not change [40, 41]. The tolerance intervals should be determined by the designer of the style and used later in its manufacturing process. These values will depend on the material properties, design concept and market strategy of the brand. Brands which manufacture products with a higher price level will use smaller tolerance intervals to keep more precisely the originally developed design idea of the final product. The fast fashion brands will be able to use larger tolerance intervals for their goods, keeping the same general design idea but reducing material use and the product price more seriously.

The experiments with all garment styles showed that even minimal reduction of the widening or length of the tested styles can give noticeable fabric savings. Obviously, it is very important already in the style development process to find minimal values of those construction parameters which directly influence fabric use. As it is inefficient to create a large number of samples, a new tool is needed to determine precisely and efficiently all tolerance intervals for a style. Currently, the industry uses CAD for visualisation of 2D patterns as 3D garments on acomputer screen [30]. However, the effect of slightly changed length or widening of the style cannot be seen in a reduced size. The software could be supplemented with a projector to evaluate virtual 3D garment samples easily in their real size, and hence to see the influence of slightly changed construction parameters on the original design concept. This kind of tool could be very valuable in any garment style development process, as it could help to reduce time, raw material use and the number of first samples tested.

The experiments with all tested styles showed that a reasonable reduction of widening or length affected material consumption more, and less marker efficiency. The *fabric use efficiency* influences the amounts of pre-consumer waste obtained in the material cutting process. This part of fabric waste is much smaller than post-consumer waste, and there are already methods developed and ways to reuse or recycle them [33, 34, 42]. *Fabric consumption* directly influences product price and also post-consumer textile waste, which is obtained at the end of the life-cycle of the product. In the current situation, post-consumer textile wastes are weakly recycled because of a lack of methods to do it in an efficient way [34, 42, 43, 44]. Therefore, it is very important to reduce post-consumer textile waste, and with it serious environmental problems created by it. In the current situation the reduction of post-consumer textile wastes and, hence, product price, has already become more actual than the reduction of pre-consumer material wastes.

More detailed analyses of the markers created were not performed as the experiment with styles tested cannot represent nesting results of manufacturing orders for different other garments. However, the experiments proved the hypothesis that the *flexible design of the garment style can ensure certain fabric savings*, and with it, reduced pre- and post- consumer material wastes. As further improvement of fabric use efficiency with the help of technical innovations is already very much limited [40, 41], the possibility to influence it by flexible style design has to be taken into serious consideration.

7. Methodology of the work process using tolerance intervals

The authors of the paper “ *The environmental price of fast fashion”,* talking about the future of the fashion industry, conclude that “it is needed to create a new system which ensures creativity and collaboration between designers and manufacturers [10]. How? There could be one common software, with the help of which the tolerance intervals determined by a designer are easily used later in the product manufacturing process. Work methodology could be the following:

1. On the basis of the designer’s sketch, pattern pieces are created for a basic size.
2. Using software for visualisation of 2D patterns as 3D garments and a projector, a real size virtual sample is created for the style. The tolerance intervals - the smallest and largest values of certain construction parameters (widening, length, width, and others), which can be used while not changing the initial design idea of the style - are determined.
3. Sets of pattern pieces for all needed sizes are created by pattern grading software in a fully automated way.
4. If it is necessary, previously determined tolerance intervals (their smallest and largest values) for new sizes are checked by the software for visualisation of 2D patterns as 3D garments.
5. Several sets of pattern pieces are created for every size using different values of construction parameters in their tolerance intervals. For example, 3 sets of pattern pieces are created using the smallest, medium and largest widening values, or more sets are created, depending on the style, fabric properties and volumes of the tolerance intervals. All generated sets of pattern pieces for all sizes are stored in the data base of the system.
6. Large numbers of markers are created and screened using all previously generated sets of pattern pieces and the manufacturing order data: ordered quantities, fabric types and colours, fabric width and length, spreading and other settings. Finally the best markers are selected to ensure the most efficient fabric use for every unique manufacturing order.

The work methodology offered is not complicated and can be used by industry even now. The tolerance intervals can be determined with the help of software for visualisation of 2D patterns as 3D garments (Modaris 3D by Lectra, AccuMark 3D by Gerber, PDS 3D Optitex, CLO 3D by CLO, VStitcher by Browzwear, Tuka 3D by Tukatech, 3Dress by Morgan Technica) and physical samples of the style. A wide range of pattern making and grading software is available that can be used to create sets of pattern pieces using different values of their construction parameters in the tolerance intervals in a fully automated way (Modaris by Mectra, AccuMark by Gerber, PDS 2D by Optitex, TUKAcad by Tukatech, Pattern Designer and Nest expert by Kuris, and many others). Later, already in the product manufacturing process, a huge number of markers can be created and screened in a fully automated way using software like: Flex Offer by Lectra, AccuPlan by Gerber, CutPlan by Optitex, Mastermind by Morgan Technica, Cut Planner by Gemini, FKAD Wom Plan by FK Group, Spread&Cut

Planner by Kuris, Cut Planning by Polygon, and others [32].

However, to make the work process maximally efficient and transparent to all staff involved in the garment designing and manufacturing processes, one common cloud-based software should be used. It has to unite pattern making and grading, visualise 2D patterns as 3D real size garments (adding a projector) and also cut planning software. Its centralized database has to be transparent and easily available for all its users (from the designer to cutting room operators). Information obtained in every work phase should be automatically transferred to other users. Thus, after determination of tolerance intervals, the system could by itself, in a fully automated way, generate all possible sets of pattern pieces to keep them ready in the database of the software for the next work phase. When manufacturing orders are known, the system creates an unlimited number of markers to find the best solutions depending on the set priorities. The priorities could be the following:

- to get the maximally minimal use of material for the order using *the same values* of construction parameters in their tolerance intervals (widening, length, and others) for all sizes of the garment style,
- to get the maximally minimal use of material using *different values* of construction parameters in their tolerance intervals for different sizes. For example, to find an individual widening level for every size, and to create every marker with the minimal length and highest fabric use efficiency possible.
- to get the best compromise between efficient material use and the use of the largest possible values of construction parameters in their tolerance intervals. For example, finding the largest widening of the skirt while still ensuring one of the smallest material consumption and best material use efficiency for the order.

In real time the designers and company's management would be able to see final 3D visualisations of the style (one or all sizes) and accept or reject them before the unique production order is compiled. Softwares which can already be used now are as follows:

1. LectraModaris 3D together withFlex Offer;
2. Gerber AccuMark (Gerber AccuMark 2D + Gerber AccuMark 3D + Gerber AccuNest) together with Gerber AccuPlan.
3. OptitexPDS 2D/3D together with CutPlan.

8. Conclusions

The authors of the paper tried to find new ways of how the MWD concept could be effectively used in the garment industry. Garment designing principles and production conditions were investigated and two experiments performed to see possibilities of how to make garment design conditionally flexible. The following general conclusions were found:

1. Currently, in the fashion industry the design idea of a product inadequately supports the MWD concept (minimal waste design). There are no efficient tools or methods available to create garments with maximally minimal raw material use.
2. Because of objective reasons, the fashion industry cannot create perfect design garments. However, traditionally the design of a garment style is kept fixed during all its very changeable manufacturing process, thereby increasing product costs, as well as pre and post-consumer fabric wastes.
3. The experiments proved that it is possible to create a single design idea with slightly different values of certain construction parameters. These values - length, widening, others - can be changed in their tolerance intervals in which the visual perception of the style does not change.
4. A huge number of pattern pieces can be developed for a single garment style using certain slightly different construction parameters in their tolerance intervals. Their further use in the manufacturing process would make the design of a garment style flexible and would help to reduce pre and post-consumer material wastes, as well as, product costs.
5. To find the tolerance intervals easily and precisely, the existing CADs for visualisation of 2D patterns as 3D garments have to be supplemented with a projector to evaluate virtual garment samples in their original size. The virtual visualization of garment samples in their original size will give the possibility to find minimal values of all tolerance intervals and, hence, to develop initial garment styles with maximally minimal fabric use. It will also help to improve the designing process generally, as well as reduce its time and the number of real samples needed to find the best design solutions.
6. Already several existing softwares can be used to implement the flexible design concept in the garment manufacturing process. However, to do it in a maximally efficient way, one common *cloud-based* software should be developed, with the help of which the tolerance intervals determined by a designer are easily used later in the product manufacturing process.
7. Determination of tolerance intervals for certain construction parameters for every garment style and their later use in the product manufacturing process will presently create a very much needed "*virtual bridge*" between designers and manufacturers and will help to realize the MWD concept in the fashion industry in an effective way.

References

1. Lorenzoni G. The Fast Fashion Business Model. Conference proceedings of the Advanced Information Systems Engineering Workshops.CAiSE 2016 International Workshops, Ljubljana, Slovenia, June 13-17, 2016, Springer. 2016; 249https://doi.org/10.1007/978-3-319-39564-7_6
2. Caro F. and Martínez-de-Albéniz V. Fast Fashion: Business Model Overview and Research Opportunities.In: Agrawal N, Smith S,editors.Retail Supply Chain Management, International Series in Operations Research & Management Science, Vol 223. 2015, Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-7562-1_9
3. Backs S, Jahnke H, Lüpke L,Stücken M. and Stummer C. Traditional versus fast fashion supply chains in the apparel industry: an agent-based simulation approach. Annals of Operations Reseach. 2021; 305:487–512. https://doi.org/10.1007/s10479-020-03703-8
4. Dobilaite V, Mileriene G, Juciene V, Saceviciene V. Investigation of current state of pre-consumer textile waste generated at Lithuanian enterprises. International Journal of Clothing Sciences and Technologies. 2017;29(4):491-503. https://doi.org/10.1108/IJCST-08-2016-0097
5. Backs S, Jahnke H, Lüpke L,Stücken M. and Stummer C. Traditional versus fast fashion supply chains in the apparel industry: an agent-based simulation approach. Annals of Operations Reseach. 2021;305:487–512. https://doi.org/10.1007/s10479-020-03703-8
6. Neumann H L, Martizen L M, andMartizen L F. Sustainability efforts in the fast fashion industry: consumer perception, trust and purchase intention. Sustainability Accounting, Management and Policy Journal. 2021;12(3):571-590. https://doi.org/10.1108/SAMPJ-11-2019-0405
7. Zakaria N,Gupta D. Anthropometry, Apparel Sizing and Design (2nd Edition);Woodhead Publishing. Cambridge.(2020). https://doi.org/10.1016/B978-0-08-102604-5.00004-4
8. Bye E, LaBat K L,DeLong M R. Analysis of body measurement systems for apparel. *Clothing and Textiles Research Journal.* 2006; *24*(2):66-79. https://doi.org/10.1177/0887302X0602400202
9. Bye E, La Bat K, McKinney E, Kim D. Optimized pattern grading. International Journal of Clothing Scienes and Technology.2008;20(2):79-92. https://doi.org/10.1108/09556220810850469
10. Niinimäki K, Peters G, Dahlbo H. *et al.* The environmental price of fast fashion. Nature Reviews Earth & Environ. 2020; 1:189–200. https://doi.org/10.1038/s43017-020-0039-9
11. Rathinamoorthy R. (2019), Circular fashion. In: Muthu S S, editor,Circular Economy in Textiles and Apparel. Cambridge: Woodhead Publishing. Elsevier. 2019;p. 13-48. https://doi.org/10.1016/B978-0-08-102630-4.00002-9
12. Vilumsone-Nemes I, Lay planning and marker making in textile cutting operations. In: Vilumsone-Nemes I, editor, Industrial cutting of Textile materials. 2nd edition.Cambridge:Woodhead Publishing, 2018;p. 13-26. https://doi.org/10.1016/B978-0-08-102122-4.00003-2
13. DeVoy J E, Congiusta E, Lundberg D J, Findeisen S. Post-Consumer textile waste and disposal: Differences by socioeconomic, demographic, and retail factors. Waste Management. Elsevier.2021; 136: p. 303-309. https://doi.org/10.1016/j.wasman.2021.10.009
14. Rissanen T, McQuillan H. Zero Waste Fashion Design. Bloomsbury. London. 2016. DOI:10.1111/fcsr.12255
15. Lei G, Li X. A Pattern Making Approach to Improving Zero-Waste Fashion Design. Fashion Practice. 2021; 13(3): p. 443-463. https://doi.org/10.1080/17569370.2021.1982503
16. ElShishtawy N, Sinha P,Bennell J A. A comparative review of zero-waste fashion design thinking and operational research on cutting and packing optimisation. International Journal of Fashion Design, Technology and Education. 2022;15(2): p. 187-199. https://doi.org/10.1080/17543266.2021.1990416
17. Saeidi E,Wimberley V S. Precious cut: exploring creative pattern cutting and draping for zero-waste design. International Journal of Fashion Design, Technology and Education. 2018; 11(2): p. 243-253. DOI: 10.1080/17543266.2017.1389997
18. Ramkalaon S,Sayem A S M. Zero-Waste Pattern Cutting (ZWPC) to tackle over sixty billion square meters of fabric wastage during mass production of apparel. The Journal of The Textile Institute. 2021;112(5): p. 809-819. https://doi.org/10.1080/00405000.2020.1779636
19. Subathra B,Vijayalakshmi D. A Look Back at Zero-Waste Fashion Across the Centuries. In: Muthu S S, editor. Sustainable Approaches in Textiles and Fashion. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry. Singapore: Springer, 2022;p.87-115. https://doi.org/10.1007/978-981-19-0530-8_5
20. Jocić S. Sustainability in Fashion: Past creativity as an inspiration for the future. Tekstilnaindustrija.2022; 70(2): p. 28-39. DOI: 10.5937/tekstind2202028J
21. Saeidi E, Wimberley V S,Precious cut: exploring creative pattern cutting and draping for zero-waste design. International Journal of Fashion Design, Technology and Education. (2018);11(2): p. 243-253. https://doi.org/10.1080/17543266.2017.1389997
22. Senanayake R,Hettiarachchige V G, A zero-waste garment construction approach using an indigenous textile weaving craft. International Journal of Fashion Design, Technology and Education. 2020;13(1): p.101-109. DOI: 10.1080/17543266.2020.1725148
23. Duarte A Y S, Sanches R A, Dedini F G. Assessment and technological forecasting in the textile industry: From first industrial revolution to the Industry 4.0. Strategic Design Research Journal. 2018; 11(3): p.193-202. DOI:10.4013/sdrj.2018.113.03
24. Black S, Haye A, Entwistle J, Root R, Rocamora A, Thomas H. The Handbook of Fashion Studies.London:Bloomsbury Publishing; 2013.https://www.bloomsbury.com/uk/handbook-of-fashion-studies-9780857851949/
25. Welters L, Lillethun A. Fashion history. Global view. London:Bloomsbury Publishing;(2018). https://www.bloomsbury.com/uk/fashion-history-9781474253635/
26. Morgan P W.Brief History of Fibers from Synthetic Polymers. Journal of

Macromolecular Science: Part A - Chemistry. 1981; 15(6): p. 1113-1131. DOI: 10.1080/00222338108066456

27. Feldman D, Polymer History. Designed Monomers and Polymers. 2008; 11(1): p.1-15. DOI: 10.1163/156855508X292383
28. Jocić S. Sustainability in fashion: The role of a fashion designer in shaping a future that is ecologically acceptable and socially responsible. Tekstilnaindustrija,2022; 70(1): p. 12-22. DOI: 10.5937/tekstind2201012J
29. Gereffi G, Frederick S.The global apparel value chain, trade and the crisis: challenges and opportunities for developing countries. Policy research working papers. 2010. https://doi.org/10.1596/1813-9450-5281
30. Jhanji Y. Computer-aided design - garment designing and pattern making. In: Nayak R, Padhye R, editors. Automation in Garment manufacturing.Cambridge: Woodhead Publishing, 2018;p.253-289. https://doi.org/10.1016/B978-0-08-101211-6.00011-2
31. Vilumsone-Nemes I. Automation in spreading and cutting. In: Nayak R, Padhye R, editors. Automation in Garment manufacturing. Cambridge:Woodhead Publishing,2018;p.139-146. https://doi.org/10.1016/B978-0-08-101211-6.00006-9
32. Nemeša I. Automated management systems to organize work process in a cutting room. Tekstilnaindustrija.2019; 67(2): p. 45-49. DOI: 10.5937/tekstind1902045N
33. Lewis T.Apparel disposal and reuse. In: Blackburn R, editor. Sustainable apparel - production, processing and recycling. Cambridge: Woodhead Publishing, 2015;p.233-250. https://doi.org/10.1016/B978-1-78242-339-3.00010-8
34. Yalcin-Enis I, Kucukali-Ozturk M,Sezgin H. Risks and Management of Textile Waste. In: Gothandam K, Ranjan S, Dasgupta N, Lichtfouse E. editors. Nanoscience and Biotechnology for Environmental Applications.Cham: Springer,Environmental Chemistry for a Sustainable World, 2019;22. https://doi.org/10.1007/978-3-319-97922-9_2
35. Nayak, R. (2020), *Sustainable Technologies for Fashion and Textiles*, Woodhead Publishing, Cambridge. https://doi.org/10.1016/C2018-0-00610-6
36. Behera, B.K. (2015), "Role of fabric properties in the clothing-manufacturing process", Nayak, R and Padhye, R. (Ed.) *Garment Manufacturing Technology*, Woodhead Publishing, Cambridge, pp.59-80. https://doi.org/10.1016/B978-1-78242-232-7.00003-5
37. Spahiu T, Canaj E,Shehi E. 3D printing for clothing production. Journal of Engineered Fibers and Fabrics.2020;15(3): p.1–8. DOI:10.1177/1558925020948216
38. Naveed T, Zhong Y, Zhicai Y, Naeem M A, Kai L, Haoyang X, Farooq A,AbroZ A. Influence of Woven Fabric Width and Human Body Types on the Fabric Efficiencies in the Apparel Manufacturing. Autex Research Journal.2020; 20(4): p.484-496. https://doi.org/10.2478/aut-2019-0044
39. Vilumsone-Nemes I. Industrial cutting of Textile materials. 2nd edition.Cambridge: Woodhead Publishing, (2018) https://doi.org/10.1016/B978-0-08-102122-4.00003-2
40. Vilumsone-Nemes I,Belakova D. Reduction of material consumption cutting garment styles from checked fabrics. IndustriaTextila.2020; 3, p. 275-281. http://doi.org/10.35530/IT.071.03.1667
41. Vilumsone-Nemes I, Kaplan V,Belakova D. Potentialities of Reducing Textile Waste in the Manufacturing of Garments from Striped Fabrics. Fibres& Textiles in Eastern Europe.2020; 6(144): p.58-63. DOI 10.5604/01.3001.0014.3799
42. Pensupa N, Leu SY, Hu Y. et al. Recent Trends in Sustainable Textile Waste Recycling Methods: Current Situation and Future Prospects. Sze C,Lin K, editors. Chemistry and Chemical Technologies in Waste Valorization. Springer, 2017, p. 189–228. https://doi.org/10.1007/s41061-017-0165-0
43. Stanescu M D. State of the art of post-consumer textile waste upcycling to reach the zero waste milestone. Environmental Science and Pollution Research. 2021; 28: p.14253–14270. https://doi.org/10.1007/s11356-021-12416-9
44. Hawley J M. Apparel recycling. Blackburn R, editor.Sustainable Apparel.Cambridge: Woodhead Publishing Series in Textiles. 2015: p.251-262 https://doi.org/10.1016/B978-1-78242-339-3.00011-X