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Article

An Inquiry into Gradable Zero-Waste Apparel Design

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Abstract: The implementation of standardized grading production practices within the mass market has been challenging for scholars experimenting with zero-waste apparel design. The purpose of this research was to test the efficacy of the Carrico Zero-waste Banded Grading (CZWBG) technique, which utilizes bands inserted in strategic locations as a method of grading zero-waste patterns across various consumer categories. An additional purpose was to evaluate the ways in which this grading approach affected the aesthetic outcomes of garments across a size run, and to determine whether this method affected the overall design process of the designers involved. Through experimental research design, six design scholars successfully tested and incorporated the CZWBG technique in zero-waste one or two-piece apparel item(s), subsequently developing three sizes in an industry-specified size range for their product category. Each design was cut from zero-waste patterns in a mid-range size and graded up and down one–two sizes using an industry-standardized grading scale. The grading was achieved by varying the widths and lengths of strategically inserted bands of fabric or trim. The designers utilized various grading methods, textiles, pattern development methods, and size runs, showing that the CZWBG technique can successfully be applied across multiple consumer categories in the apparel industry.

Keywords: zero-waste; grading; patternmaking; slow fashion



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1. Introduction

Textile waste, due to inefficiencies in the apparel manufacturing process, amasses over 60 billion square meters of fabric annually [1]. This waste is not limited to fabric, but includes fibers and yarns, dyes and chemicals used in coloration, and increasingly valuable time, labor, and money invested in processing [2]. As the global demand for apparel products grows, and because resources are commodity driven, the apparel industry continues to seek methods of sustainability to address this growing global issue. The exploration of zero-waste design methods has gained traction over the past decade [3,4]. In the apparel production process, 15 percent of cut fabric is lost due to patterns and markers (how the various pattern pieces are laid out on fabric) [5,6], and most garment markers still generate significant fabric waste. Zero-waste patterns can eliminate all fabric waste, either through the use of patterns made from whole cloth, interlocking pattern pieces, or multiple size or garment pattern layout methods [6,7]. In addition to the increased time needed

for the making of zero-waste patterns, generating the designs in a range of sizes creates challenges in the mass marketability of products [7,8]. Creating individual markers for each garment size within identified fabric width constraints is highly inefficient and costly. Thus, zero-waste designers tend to create one-size-fits-most options, customized one-off designs, or single-consumer use pattern options for home use, thus limiting mass-market applicability. Each of these approaches addresses the global carbon footprint challenge [9]. Despite the environmental benefits, zero-waste pattern design, as an apparel production approach, is not without its challenges. An analysis of 64 publicly available zero-waste patterns revealed the following six key issues: (1) the patterns often only work for one garment size, (2) the patterns only work for the intended textile width, (3) edge finishes are not considered in the pattern, (4) the pattern pieces are off-grain, (5) the patterns are not engineered for mass production, and (6) the patterns have insufficient directions [10]. Until an approach is created that streamlines zero-waste into a fully executable, integrative process in mainstream fashion, environmental and sustainability impacts will be limited [5]. While zero-waste pattern design offers meaningful design ownership and sustainable stewardship at an individual level, currently, it does not support broad-spread sustainable behavior across mass markets.

However, zero-waste contributes to the larger picture of sustainable practice in the apparel industry, building on core tenants of the Slow Fashion philosophy defined by Fletcher [11]. Slow Fashion's foundation, as defined by Fletcher, is grounded in sustainability values paired with traditional values, ecosystem preservation, a diversity of sources, and a responsible approach [11]. Freestone and McGoldrick further expanded Fletcher's definition, adding the tenant of ethical choices made by consumers [12]. Furthermore, Stefko and Steffek (2018) noted that Slow Fashion (SF)'s boundaries have not been clearly defined within academic environments [13]. In the pursuit of the characterization of sustainable practice through the definition of Slow Fashion, they presented a fashion matrix framework that evaluates Slow Fashion across eight areas of product characteristics within six key fashion segments, including the Mass Market segment. The authors note the exclusion of the sustainability factor from the fashion matrix, as it "presents an indisputable landmark cornerstone of Slow Fashion and the Slow Movement in general." This characterization of slow fashion reinforces the notion that sustainable practices such as zero-waste design fit within the philosophical model of Slow Fashion and have not gained momentum in the mass market due to the limitations of standardized production practices. However, if the production barriers to zero-waste applications in a mass-market structure could be broken, the sustainability benefits could be far-reaching globally and highly impactful. Thus, the challenge for design scholars over the past decade has been to examine the process of zero-waste design and its application to and opportunities within a ready-to-wear, contemporary apparel industry.

Design scholar Carrico [14,15], after years of exploration, developed a plausible method of resizing garments made from zero-waste patterns without making changes to the original pattern shapes and thus, the marker. In traditional apparel production, garment patterns are made in a single size and then systematically altered at key locations to create a range of sizes in a process called grading [16]. In Carrico's technique, grading is accomplished through carefully planned seam placements with varying widths of banded trims inserted. These bands grow or shrink in width, effectively sizing the garment up or down, utilizing apparel industry grading metrics, to create multiple sizes of a garment. Through the application of this technique to several prototypes, Carrico fine-tuned the approach across a range of women's separate garments and fit styles in her own research. In order to further evaluate the application of the Carrico Zero-waste Banded Grading (CZWBG) [14,17], design scholars were invited to select one of six different garment categories (athletic wear [18], menswear [19], children's wear [20], eveningwear [21], outerwear [22], and loungewear) and create a gradable zero-waste design.

The purpose of this research was to test the effectiveness of the CZWBG technique, utilizing the insertion of bands at strategic locations, as a method of grading zero-waste

patterns across multiple consumer categories. A further purpose was to determine the ways in which this grading approach affected the aesthetic outcomes of garments across a size run, and to determine whether this method affected the overall design process of the designers involved.

1.1. Contextual Review

In research through practice, “a contextual review is similar to a literature review but extends more broadly to include a critique of other media, interviews, exhibits, and artifacts” [23] (p. 214). Thus, we discuss not only previous scholarship of zero-waste fashion design but also the context of standard apparel manufacturing processes and what is available on the market. This review provides a holistic understanding of the problem in context, allowing for solutions that are more meaningful.

1.1.1. Grading in the Apparel Manufacturing Process

Apparel products are designed and manufactured for a range of customer categories and product types [24]. Garments must be produced in sizes to fit most customers within each market category [24]. The process of generating garment patterns in a range of sizes from an original is called grading [25]. Typically, the garment sample is produced in a size in the middle of the range, and then incrementally graded into larger and smaller sizes [16]. Thus, a new set of pattern pieces is created for each size in which the garment will be produced.

The individual pattern pieces are not simply enlarged or reduced a uniform percentage from the original to resize. Instead, the pattern pieces grow systemically to accommodate standard body sizes, which have greater variances in girth than height. For example, the bust circumference for a standard female customer may increase 3.8 cm between two sizes, but the length from shoulder to waist may only increase 0.6 cm. Additionally, while bust, waist, and hip girths tend to increase and decrease by uniform amounts between sizes, the neck, arm, thigh, and other girths all scale at different rates from the former. Therefore, all of the pattern pieces used to construct a garment must be analyzed before grading to determine where the pieces will grow, if they grow at all, in order to maintain the proper fit for each size while also preserving the silhouette and style lines of the garment [16]. A simple method of grading a bodice pattern is to slash the pattern along the lines illustrated in Figure 1. The cut lines can then be overlapped specific amounts for smaller sizes and spread out for larger sizes.

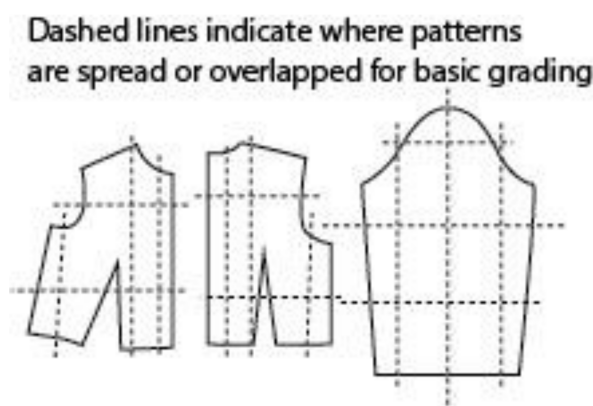


Figure 1. Illustration of the slash lines for grading.

1.1.2. Scholarship of Zero-Waste Patternmaking

Several exhibitions focusing on zero-waste designs have been mounted in recent years to support and promote the practice, including YIELD in the United States and New Zealand [1], Zero-Waste: Fashion Re-patterned in the United States [14], and Make/Use in New Zealand [15]. In addition, at the design exhibition during the annual conference

for the International Textile and Apparel Association, the number of professional, sustainable designs being made with zero-waste methods steadily increased between 2012 and 2016; in 2016, 34% of sustainability-themed pieces were zero-waste or produced minimal waste [26].

1.1.3. Apparel Mass Production with Zero-Waste Patternmaking

While zero-waste has become a popular way for some fashion designers to integrate sustainability into their work, the overwhelming majority of the apparel sold today is not made with zero-waste patterns. Few designers have bridged the gap between creating a single zero-waste garment (as shown in an exhibition) and marketing multiple designs in the ready-to-wear market. Tara St. James is one designer who is well known for sustainable practices with her label, Study NY, and she advertises some of her pieces as zero-waste. While her zero-waste Kimono Dress is available in two sizes (XS/S and M/L), her Square 1 dress is sold as a “one size fits most” garment [27]. Yeohlee is another brand with select items that are zero-waste; in fact, the Fall 2015 collection offered a zero-waste pant, jacket, and skirt in a size range from 2–12. The same collection also featured a zero-waste rain coat, which was only one-size-fits-all [28]. A one-size-fits-all garment may be feasible for a small number of apparel items, and may suit some consumers. However, in order to fully assimilate a sustainable practice like zero-waste into today’s fashion markets, zero-waste garments will need to resemble current apparel assortments in the ready-to-wear category, which includes being available in a range of sizes [9].

Cut and sew fashion production uses standard fabric widths, and a designer must work within those widths. Traditional garment grading methods, then, would not work within a zero-waste pattern layout because there is no negative space available for expansion to larger sizes, nor is there allowance for reduction to smaller sizes. Because “it is not possible to grade a zero-waste garment in a conventional manner if the intention is that all sizes are zero-waste” [29], p. 137, designers must explore other ways to offer a range of sizes for zero-waste garments.

Strategies for offering sizes of zero-waste garments beyond the one-size-fits-all approach include working with different fabric widths for each size, redesigning a pattern for each size, and applying traditional grading techniques to the patterns, followed by rearranging the layout [29]. Additionally, the patterns for different garments and sizes can be combined in one marker to utilize all of the fabric. Holly McQuillan designed a top in sizes small, medium, and large that is cut zero-waste when the small patterns are placed in the marker alongside the large patterns [30]. The resulting tops are the same length, which is a diversion from conventional pattern grading rules. The zero-waste “woodgrain” dress by the Australian brand Material By Product was produced in a range of sizes by altering the amount of fullness consumed in its pleats and folds. In reference to the difference in fullness between sizes, the designer, Susan Dimasi, states, “no two sizes are the same” [31] (8:42). While these designers kept the general aesthetic features constant in the graded garments, they did not strictly adhere to conventional grading rules for length or fullness proportions. Further research is needed to develop apparel-industry-ready solutions to the problem of creating zero-waste garments in a range of sizes.

1.1.4. Slow Fashion and Zero-Waste

While not all slow fashion is zero-waste, the reduction of textile waste is a principle of the slow fashion movement [32]. Slow fashion is democratized [11] for consumers and those who create and produce it. Creating garments by a zero-waste pattern cutting methods removes apparel industry hierarchies and requires significant collaboration between the designer and patternmaker. This is a deviation from the traditional structure in apparel manufacturing, in which designers dictate the look to the patternmakers [6,29]. Slow fashion emphasizes sharing and transparency [33], especially related to the provenance of materials used and labor hired for garment creation. Zero-waste, too, has a practice of sharing; it is common for designers to share copies of their pattern layouts for zero-waste

garments. Traditional garment manufacturers generally do not make such proprietary knowledge public. A final common thread that runs through both slow fashion and zero-waste is one of time. Zero-waste pattern cutting takes considerably more time to execute than most ready-to-wear apparel [8]. Similarly, slow fashion demands that designers not to be rushed and be able to plan well [34].

1.2. CZWBG Origins

When designing the Boho Blouse, Carrico first realized the potential for the creation of a zero-waste pattern that could create garments in a range of sizes [17]. The blouse design did not start with that goal, but the idea emerged as the design progressed. The plan for the Boho Blouse was a billowy, peasant-style top with lace inserts. Employing “inquiry derived from practice” [23] (p. 214), Carrico knew from experience creating zero-waste patterns that simple straight-edged geometric shapes interlock better in the pattern layout than do shapes with concave and convex curves. Therefore, she began the design of the blouse by draping rectangles and squares of muslin on the dress form. Similar experiences lead to approaching the sleeve more like a raglan sleeve than a set-in sleeve based on how the pattern shapes would relate in the marker. The front bodice pieces needed a vertical division but additional width to maintain a zero-waste layout; thus, flat lace inserted between them provided the necessary increase in width across the bodice. For design cohesiveness, more flat lace was added to other parts of the blouse. The placement of the lace pieces brought to mind the lines in Figure 1 used for the grading of patterns, as the locations of the lace inserts were places where the garment size could be reduced or enlarged. Carrico theorized that by changing the widths of the lace trim, the blouse could be made in varied sizes without changing the original pattern shapes. Further analysis of the design upon completion proved this line of inquiry to be correct.

After completing the blouse, Carrico tested the design approach to see if inserted trims could be used for size changes on other zero-waste garments. The method was applied to a skirt, pants, and a fitted top [15]. The skirt is a straight silhouette with diagonal seams and an elastic waist. Similarly, the pants have diagonal seams that spiral around the leg. Then, the method was tested on a zero-waste sleeveless top with a fitted midriff. The top has vertical princess seams at the midriff, along with side seams. The amount of change in size was predictable due to the vertical seams. However, the change in size was also uniform for the waist and midriff’s top and bottom edges. Because the front bust pattern piece is on the bias, it could be manipulated to fit the range of sizes from 4 to 8. The top is limited in size ranges without modifying the shape of the bra/bust pattern piece. Further testing the method, Carrico created a different skirt and blouse in which “the pattern shapes remain constant across the size range while different garment sizes are achieved by varying the width of the narrow trims inserted at strategic points” [14] (p. 1).

2. Research through Practice: Multi-Category Testing Methodology

Six design scholars (called designers for the remainder of this work) used an experimental research design to evaluate the feasibility of the CZWBG method across six contemporary apparel categories. The designers were asked to test the applicability of Carrico’s method by creating a one- or two-piece apparel item(s) using a zero-waste pattern method and applying the CZWBG grading method to create three sizes in an industry specified size range for their product category. Each design was patterned in a mid-range size and graded up and down one–two industry standardized sizes using the CZWBG method. The designers were asked to document and evaluate the steps in the process, and to conduct final product evaluations of the fit and aesthetic review.

In an initial research meeting, the designers selected from the following categories based on their design expertise and background: childrenswear, menswear, outerwear, lingerie/loungewear, plus size, evening/cocktail, and athletic wear. Discussions about experience in zero-waste, the desired product category, and the agreed-upon parameters were conducted. Carrico presented a summary of prior work using the CZWBG method

and her successful approaches. Guidelines were presented and agreed on, including details of grainline use, fabric guidelines, patternmaking approaches, the use of selvages, and the design process.

A multi-page Research Process Documentation form (Appendix A) was created and distributed to the members. The pages included (a) Process Documentation, (b) Design Specifications, and (c) the Zero-waste End Product and Process Evaluation and Narrative. The Lamb and Kallal FEA six-step model [35] was used as a framework for the design process. The Process Documentation page of the form required the design scholars to document the dates, time spent, time period, project goals, achievements, challenges, and photos for each work period. Early in the design process, the designers were asked to complete the Design Specification page of the form documenting the apparel category, fabric(s) to be used for self, band and combo, size range, mid-size choice, extended sizes, and fit (fitted, moderate fit, or loose fit) of the garment.

The guidelines for the design process were fairly broad in order to allow the designers to utilize their own approach to design. The designers could utilize manual flat patterns, computer-aided patternmaking, draping, or 3D modeling to complete their design prototypes. Additionally, the markers for the zero-waste design could be hand drafted or computer generated. The designers could work from half scale and transition to full scale as desired, or begin in full scale. The requested guidelines required that the designers (1) create one mid-range sized zero-waste pattern for their chosen product category; (2) accomplish grading through the use of inserted bands for each garment size produced, where the band width varied and expanded at different rates; (3) work with bands on the straight of grain or bias where the bands could cross each other in the design; (4) execute the garment in a base size and at least one larger and one smaller size (a total of three sizes); (5) use mass production techniques for apparel construction; (6) select the fabric and fabric width determined by appropriateness for the product category; and (7) use all selvages if possible. The designers were reminded that manufacturability at a mass level was the goal to keep in mind.

Periodic virtual meetings of the group were held for updates, process alignment, discussions, and trouble-shooting. Time frames were created to keep the scholars on pace, and the designers were encouraged to submit their work to an international exhibition and competition. Upon the completion of the three zero-waste garments, the designers were asked to submit their Research Process Documentation form (Appendix A) with photographs.

Following the design process, the six designers met virtually to discuss their outcomes, the gradable zero-waste design process, and the resulting research project. At this meeting, it was determined that an additional Process Assessment form (Appendix B) should be completed by each designer in order to accurately capture their thoughts related to the outcomes of the research. The assessment form was used to collect data on what worked well and what did not through the stages of (1) Conceptualization, (2) Preliminary Design/Patternmaking/Draping, (3) Implementation/Construction, and (4) Evaluation. The designers were asked to assess the fit, function, and aesthetics of their resulting garments. Feedback was gathered on the challenges and strategies for the documentation process; perceived issues with taking the design to the mass production stage at the various levels of fabrication, patternmaking, cutting, assembly, and cost; and the aesthetic review of the final garment across all of the constructed sizes. A compilation of all of the datasets was completed, and a final summary of feasibility was drawn. The results are presented below.

3. Results

3.1. Demographics

Six academic designers participated in the research project. The designers had a range of experience in academic design ranging from 6 years to 25 years (an average of 15 years). The six designers teach apparel design courses and actively participate in

peer-review apparel design exhibitions. Six different categories of apparel (menswear, childrenswear, outerwear, athleisure, cocktail/eveningwear, and loungewear) were chosen by the designers to represent a wide range of possible consumer applications for this approach. A range of fabrics was chosen based on the target consumer groups; they appear below (see Table 1).

Table 1. Design outcomes information.

Designer	Consumer Category	Fabrication	Industry Size Standard Referenced	Sizes constructed	Band Grain
Designer One	Athleisure	95% Polyester/ 5% Spandex Double knit	Moore, Mullet, & Young, (2015)	S, M, L ¹	Straight of Grain and Cross Grain
Designer Two	Menswear	100% linen plain weave	Hanford (2003)	M, LG, XL	Straight of Grain
Designer Three	Childrenswear	100% cotton plain weave	Hanford (2003)	3, 5, 6x	Straight of Grain
Designer Four	Cocktail/eveningwear	100% Polyester Satin; 100% Nylon embroidered lace	Mullet (2015)	4, 8, 12	Straight of Grain
Designer Five	Outerwear	100% cotton canvas	Mullet (2015)	6, 10, 14	Straight of Grain and Bias
Designer Six	Loungewear	100% silk taffeta, 100% nylon lace	Mullet (2015)	4, 6, 8	Straight of Grain

¹ Sizes XS and XL were tested on virtual models.

The results were compiled from two major sources of data: self-reported Research Process Documentation forms (Appendix A) and Process Assessment forms (Appendix B). The design process forms were completed by each designer while working through their creative process. The assessments were completed following the completion of the gradable zero-waste design activities. Each designer reflected on their outcomes and recorded them.

3.2. Self-Reported Design Process

Overall, the designers spent most of their time in Stage 4: Prototype Development (an average of 24.208 h spent). The Problem Identification stage was the least frequently documented by the designers (an average of 1.667 h spent). The average amount of time spent completing the design project was 49.625 h (see Table 2).

Table 2. Time spent (hours) per design stage.

Designer	Stage 1 Problem ID	Stage 2 Preliminary Ideas	Stage 3 Design Refinement	Stage 4 Prototype Development	Stage 5 Evaluation	Stage 6 Implementation	Total
Designer One	3.5	1.5	5	35	7	17	69
Designer Two	1.5	3.5	5.75	12	10	8.5	41.25
Designer Three	2.5	1.25	1	27	0.5	0	32.25
Designer Four	0	3	10.5	34.5	0	0	48
Designer Five	1.5	2	32.5	26.5	0	19.5	82
Designer Six	1	1	13	10.25	0	0	25.25
Average Time Spent	1.667	2.042	11.292	24.208	2.917	7.5	49.625

3.2.1. Conceptualizing the Project

When approaching the gradable zero-waste project, many designers chose to begin their process with research. For instance, Designer Five started with “a lot of research about zero-waste patterns . . . I looked at the actual pattern layouts to see what shapes were common and how designers were dealing with areas of the pattern that are typically curved.” Looking at the markers of other successful zero-waste designs was a common

strategy of the designers. Two designers created designs from shapes that would be easier to use in a zero-waste marker, Designer Six used diamond shapes, and Designer Four focused on rectangles. Multiple designers also mentioned that they visualized the specific pattern shapes that might cause issues in a marker early on. Crotches, hoods, and armholes were mentioned as challenging pattern shapes that would have to be addressed while creating the zero-waste marker. A few of the designers also specifically researched classic styles or consumer needs for their specific apparel categories.

Other major considerations when approaching this project were the grading and where to place bands. Considering the possible placement of the bands before designing was a consideration made by all of the designers. For example, Designer Four stated that “I was able to get a design envisioned based on where the grading bands naturally lay on the body—I’ve always thought these were placed in an aesthetically pleasing manner, so I wanted to highlight this with my design.”

The designers detailed various conceptual challenges with their projects. Some felt that their categories did not lend themselves to the grading band method, i.e., “There is not a ‘good place’ to add in the bands for many styles without visually ruining the garment style and aesthetics” (Designer Three). Others described a trial and error process when determining how to create the zero-waste marker.

3.2.2. Preliminary Designs

Either a flat pattern or draping was used to generate the initial garments. The designers then created possible zero-waste markers with the initial pattern pieces and adjusted the pattern shapes or added new design elements (such as pockets or bows) when unused areas presented themselves on the marker. As part of this process, some of the designers created small-scale paper patterns to test their design concepts as they evolved. Designer One said, “I did go back and forth [between working on the computer and working] with printed small scale pattern pieces initially which satisfied my need to touch and feel the patterns, plus it helped to lay them out and look at ways the pieces could be placed.” In contrast to this approach, one designer relied on diamond-shaped pieces that fit in the zero-waste marker, and then draped those on a dress form to fit the body.

Another major consideration when working on the preliminary design ideas was the grading bands. The designers described having to think through not only the initial garments but also how the graded sizes would be accomplished. Designer Three stated, “Using the band-insertion method of grading requires more in-depth knowledge of grading than typically required of designers. Grading must be considered at the initial concept phase.”

The fabric selection posed yet another set of possible issues for the designers. The fabrics had to be selected early in the design process to create the zero-waste marker. One designer exclaimed, “First, I designed the whole thing for 45” wide fabric, but I couldn’t find 45” wide fabric, so I had to redo the layout for 58” wide” (Designer Four). Another designer said that the “grainline of the ZW pattern pieces should stay consistent if there are any nap, pattern, or nuance issues with the fabric” (Designer Two).

The selection of the band material was of equal concern. The designers considered drape compatibility when selecting the band material. Designer One stated “I think the use of the same fabric with two tones was beneficial, not just for aesthetics but also for fit and sewing because it was sewing like materials together—They agreed in stretch and drape.” Designer Two also noted of the band material that “The most critical is alignment of weight and fabric structure to the self [primary] fabric.” The outerwear and loungewear looks did present challenges with the band materials. “After my first half-scale muslin, I discovered I needed to replace my collar, cuffs, and hem band with rib knit. This allowed these pattern pieces to adjust to the new width of the jacket bodice” stated Designer Five, whose final jacket used three different materials for the bands. The choice of a rib knit at the collar, cuffs and hem was appropriate for the bomber-style jacket. Additionally, Designer Five chose to cut a portion of their bands on the bias grain in order to allow for stretch

when attaching the bands to the curved princess seams of the jacket. All of the bands from this textile were also cut on a bias for consistency and to eliminate waste. However, the drape of the garment was not affected negatively by the change in the grainline due to the finishing technique used on the inside of the garment; each band is backed in another band, creating stability. Designer Six did experience a slight difficulty when joining the lace to the silk taffeta in the loungewear, and decided “Strips of illusion sewn in first before applying the lace would make the lace application easier, but add cost and time to the garment” (Designer Six).

3.2.3. Implementation

The first muslins revealed issues that had to be solved, such as requirements for additional grading bands, the order of the sewing operation requirements, aesthetic elements that were unsuccessful, and the need for precision sewing. The designers were able to address these issues and move to the creation of their final design prototypes. When creating the prototypes, Designer Three remarked, “Because the main fabric marker was the same for all three sizes, I could layer the fabric and cut these three different sizes with the same cutting stroke. Layered cutting of different sizes was more efficient and would not be possible with a regular multi-size marker.” The results of Designer Three’s layered cutting are shown in Figure 2.



Figure 2. Side and back views of the child’s dress, executed in three sizes.

Other designers commented that the sewing was fairly simple. Two designers noted that while the sewing was straightforward, the order of operations was highly specific for these garments, and did cause some issues. Designer Two stated, “Because of the number of inserted bands and intersecting and matching seams, construction order was critical.” Additionally, the designers found that given the number of seams with the inserted bands, precision in sewing was an absolute requirement. Designer Four commented, “I had to spend a ton of time making sure all my lines were exact and perfect.” Figure 3 shows three sizes of the dress achieved by Designer Four. Other designers noted that in some cases, varying seam allowances had to be employed in order for each size to fit properly. Designer Six stated, “I had to make the SAs smaller on several of the pieces. The seam allowances are not consistent across the entire garment.” The flat drawings and garment photos of the implemented designs are presented in Table 3. The zero-waste pattern layouts are shown in Table 4. The pattern pieces are color coded to show their alignment with the corresponding garment parts. Notice that the markers shown in Table 4 do not include

bands, as they do not remain constant across sizes. The designers cut the bands from fabric or used pre-existing narrow trim such as lace. As noted in Table 1, the grain direction of the rectangular bands varied.



Figure 3. Front views of cocktail/eveningwear dress prototypes in three sizes.

Table 3. Photos of the completed designs and garment flats.

Designer and Category	Front View and Back View	Flat Drawing with Gray Indicating Band Locations
Designer One, Athletic wear	<p>Two photographs of a purple athletic top on a mannequin. The left photo shows the front view, and the right photo shows the back view. The top has a hood and long sleeves.</p>	<p>A technical flat drawing of the purple athletic top and skirt. The top is shown in front and back views, with a gray band across the chest and another across the back. The skirt is shown in front and back views, with a gray band at the waist. A label 'Back without skirt piece' points to the back view of the top.</p>

Table 3. Cont.

Designer and Category	Front View and Back View	Flat Drawing with Gray Indicating Band Locations
Designer Three		
Designer Four		
Designer Five		
Designer Six		

Table 4. Color-coded flats and corresponding pattern layouts.

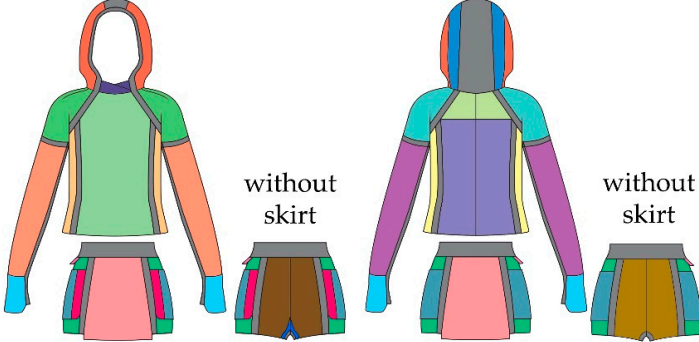
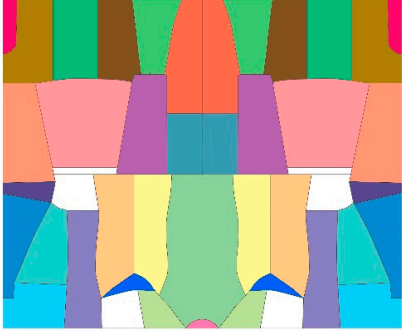

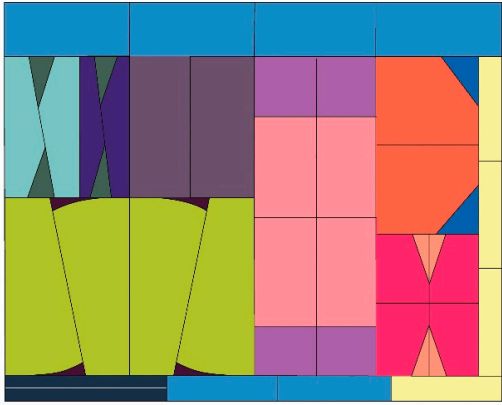

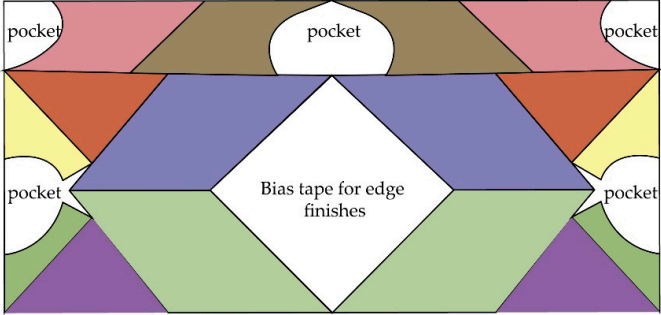
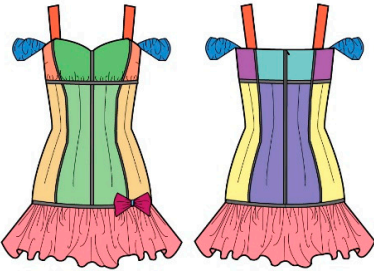
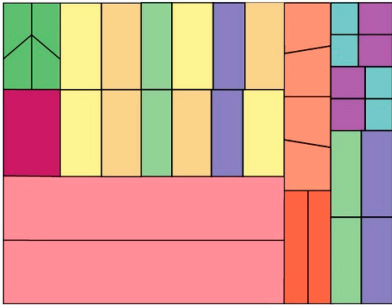
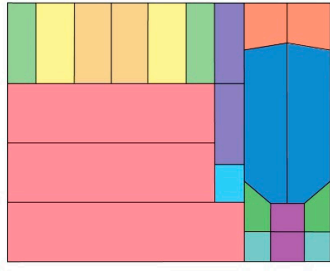
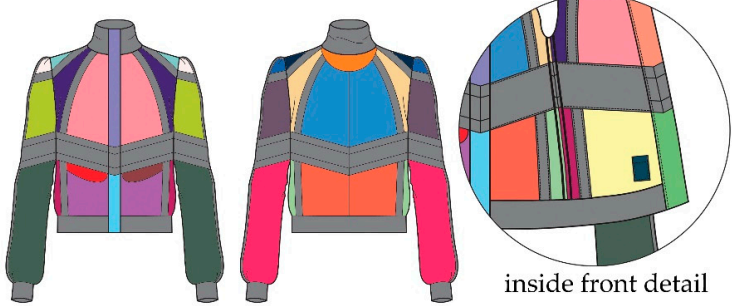
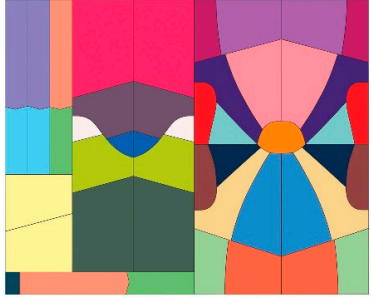

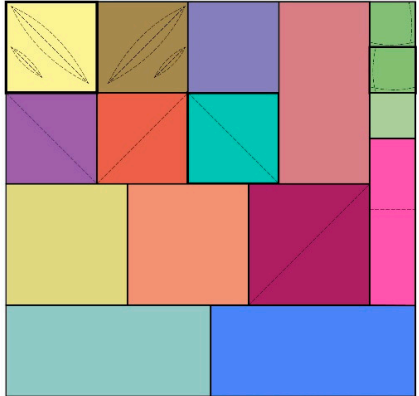
Designer	Flats and Patterns ¹	
Designer One		<p data-bbox="1187 365 1382 394">119 cm × 146 cm</p>  <p data-bbox="1086 734 1489 763">white indicates pockets and interior finishes</p>
Designer Two		<p data-bbox="1134 779 1313 808">113 cm × 152 cm</p> 
Designer Three		<p data-bbox="1050 1249 1206 1279">52 cm × 112 cm</p> 
Designer Four		<div style="display: flex; justify-content: space-around;"> <div data-bbox="836 1624 1027 1682"> <p data-bbox="836 1624 1027 1682">Base fabric 112 cm × 145 cm</p>  </div> <div data-bbox="1187 1624 1394 1682"> <p data-bbox="1187 1624 1394 1682">Lace overlay 103 cm × 128.5 cm</p>  </div> </div>

Table 4. Cont.

Designer	Flats and Patterns ¹	
Designer Five		<p data-bbox="1209 367 1385 396">92 cm × 114 cm</p> 
Designer Six		<p data-bbox="1193 748 1385 777">136 cm × 132 cm</p> 

¹ All patterns shown with straight of grain vertically oriented.

In order to further demonstrate the grading method with one example from the study, Designer One created Tables 5 and 6 below. The tables show the hip circumferences for the top and skirt she created. When determining the amount of grade necessary between sizes, the designer referenced existing grade rules, as well as size charts [16]. Without any bands, the hip circumference of the top was 91.44 cm. Designer One determined that one band placement would need to be at the side seam in order to allow for armhole and sleeve growth. Additional bands were placed near traditional princess seam locations because the zero-waste pattern accommodated their placement well. Because chest and hip circumferences grade similarly, all of the vertical bands were the same width within a size. Thus, six bands around the body of the top evenly distributed the necessary grade between each size. Figure 4 shows virtual renderings of the left side views for sizes XS and XL, where band placement can be viewed. Because the skirt had compression while the top did not, the hip grade of the skirt differed. Without bands, the skirt pattern measured 77.72 cm at the hip. In order to achieve the desired 80.26 cm for size XS, Designer One inserted four bands, each measuring 0.635 cm wide. The decision to split each side of the skirt to insert two bands was made to allow for a consistent pocket construction and appearance. Of course, other bands were used in the garments to achieve other grades between sizes. For example, the hood center band widens as the neck grows (due to diagonal armhole bands), and the hood band grows in length to allow for modest growth in the center back length of the top.

Table 5. Hem circumference for Designer One’s top. All of the measurements are in centimeters.

Size of Top	Grading/Growth Needed	Number of Bands	Width of Bands in	Hem Circumference for the Top
Pattern without bands				91.44
XS	3.81	6	0.635	95.25
S	8.38	6	1.397	99.82
M	13.41	6	2.24	104.85
L	21.03	6	3.50	112.47
XL	28.65	6	4.78	120.09

Table 6. Hip circumference for Designer One’s skort. All of the measurements are in centimeters.

Size of Skort	Grading/Growth Needed	Number of Bands	Width of Bands	Hip Circumference for the Skort
Pattern without bands				77.72
XS	2.54	4	0.635	80.26
S	5.08	4	1.27	82.80
M	10.16	4	2.54	87.88
L	17.78	4	4.45	95.50
XL	27.94	4	6.985	105.66

**Figure 4.** Sizes XS and XL for Designer One’s athleisure wear, left side view. The tops are shown without sleeves for a better side view. The skort is shown without its skirt and pockets.

3.2.4. Evaluation

Overall, the designers were happy with their resulting work. Many of the garments had a fit that “does not look like a typical zero-waste garment that usually does not have a close fit to the body” (Designer Five), making the garment more marketable and successful according to the designers. Three designers specifically commented that they felt their garments were aesthetically superior to typical zero-waste designs because a close fit was achieved.

When considering the band grading method, many of the designers felt it was successful. Designer Three commented that the use of bias bands on her design provided “some ‘give’ in the circumference of the dress”, making it easier for the target consumer to don and doff the garment. Each designer fully acknowledged that the band grading method would create differences in the aesthetics for the three different sized garments. As Designer Three stated, “The aesthetics of each sample was pleasing; however, their proportions did differ.” Designer Six was the only designer who utilized lace for her bands. She pointed out that sourcing multiple different widths of lace to create each size could be tricky.

Some of the designers felt that one of their graded sizes was less aesthetically successful. For instance, “In the smallest size, I do not like the size difference between the bands. The vertical bands are much narrower and look ‘wimpy’ to me” (Designer Five). Figure 5 shows three jackets by Designer Five, executed in different sizes.



Figure 5. Back views of the jacket by Designer Five. Note that black bands were utilized in the shoulder area of the size 10 garment.

There were some drawbacks to this method. Some of the designers discussed the limitations that would be encountered when using this method. For instance, creating more than five sizes in a run would most likely result in less aesthetically pleasing garments, as the bands would be too large or small proportionally. Designer Six utilized diagonal grade lines, and worried that, “The diagonal lines added not only girth but also length to the design as the sizes would increase, the result could be a garment that would be too long, and the portions would be thrown off.”

It was common among the resulting graded garments that small alterations had to be made to create the final design across the three sizes. For instance, one designer had to vary the depth of the sleeve cap pleats between the sizes to accommodate the growth. Another created a gathered skirt that did not feature any grading bands; thus, it was slightly less full in the largest size. The seam allowances were also sometimes varied across the sizes. While these slight changes did affect the aesthetics, the designers felt that changes between sizes were acceptable.

A few designers also commented on whether consumers would accept the aesthetic changes occurring when using this method in a size run. Designer One mused,

I do wonder how much consumers would notice in a store/shopping situation. I could see if one was shopping online and only saw a small garment image and ordered a large how they might notice the band width difference, but if someone is grabbing the garment off a rack in the store, would they notice the difference in band widths across the sizes? If they noticed, would that bother them?

Designer Two determined that it “may take clarifying and marketing approaches to educate the consumer.”

3.3. Documentation Process

As part of the research, each designer was asked to document their design process carefully. Some of the more successful documentation strategies were the photographing of each step of the work and automatically dropping the files into a digital folder. The photos were time and date-stamped, allowing the designers to easily return and calculate how much time was spent on each stage of the work. Designer Three used the Capture App because it “saves the date and time, so it is easy to keep track of the order and time used for steps.” Other successful tips were to write down the information at the end of each design session before the details could be forgotten.

Some of the drawbacks related to the documentation process related to remembering what had been done. Additionally, two of the designers commented that documenting disrupted the flow. Designer One stated, “It is just hard to stop and record one’s thoughts while working. Once I’m in the flow of problem-solving, I just need to stay in that mode and not pause to document.” It would be beneficial to find a method of documentation that would not disrupt flow while allowing designers to capture their thoughts.

4. Discussion

The goal of this research was to test the Carrico Zero-waste Banded Grading technique, which utilizes bands inserted in strategic locations as a method of grading zero-waste patterns across various consumer categories. The participating designers created six zero-waste garments in various consumer categories, and utilized CZWBG to grade two additional garments from the initial size. All six designers successfully created a gradable zero-waste garment which was appropriate for their chosen consumer and product category. Additionally, all six designers reported that they felt the CZWBG was a successful method for grading zero-waste garments. This was a significant achievement, as the designers utilized various grading methods, textiles, pattern development methods, and size runs, showing that the CZWBG technique can successfully be applied across multiple consumer categories in the apparel industry.

Past literature has expressed concerns about making zero-waste design common practice in the apparel industry. A major concern has been the execution of designs in multiple sizes [7,8]. As research has shown, when zero-waste patterns are graded using traditional methods, they no longer interlock, resulting in overlaps [15]. This project addresses these concerns by utilizing a standard zero-waste pattern layout for all sizes, and by allowing grading with inserted bands.

Previous work utilizing the band grading method for zero-waste garments was limited to women’s ready-to-wear garments [14,15,17]. Through our results, we have extended the research to show that the CZWBG method applies to various customer categories.

4.1. Effect on the Aesthetic Outcome

Overall, the designers were satisfied with their garment’s aesthetic outcomes. Most of the designers attributed their satisfaction to the ability to achieve a closer fit than traditional zero-waste garments. Band insertion significantly increased the number of seams necessary in the garment design, which could be distracting to the viewer’s eye. However, some designers relieved this distraction by cutting the chosen inserts from self-fabric, allowing the bands to blend in.

Implementing the CZWBG technique created proportional differences between the sizes. The length and girth of garments do not expand or reduce at the same rate, creating a difference in the widths of the band insertions. This difference becomes more apparent the further the design is graded from the mid-range size.

4.2. Effect on the Design Process

Patternmaking is integrated into the zero-waste design process. Furthermore, the textiles must be selected before the zero-waste pattern development processes can be completed, as the pattern layout will depend on the width of the chosen textiles. Compatible materials were used for the bands and garments throughout in order to ensure that there was no change of drape, and to facilitate construction. Each designer had to consider the pattern layout from the beginning of the design process, a step that usually is not taken into account in traditional garment productions until the garment is fully designed. Designers Four and Six first considered their pattern layouts using rectangles and diamonds in order to utilize the full width of their textile efficiently. Once the layout was established, they then used the shapes to drape and develop their garment designs. As the design took shape, they altered their pattern layouts to accommodate changes in their design. This process shows how the patternmaking became intertwined with the garment design process, and ultimately significantly affected the final aesthetics.

One major finding of this study was the inability to grade patterns exclusively using diagonal band insertions. Diagonal bands increase the garment proportions more in width than length, causing larger sizes to be too short for the wearer. This finding was demonstrated in Designer Three's garment. Designer Three began the grading process using diagonal bands intersecting at the corners of their patterns, such that the band would add to the length and width at the same time. However, when this method was tested, Designer Three realized the effect on the garment proportions. As a result, Designer Three added bands at the side seams and shoulders of their design, effectively balancing the garment proportions (see Figure 2).

Grading also became an integral part of the garment design process, as it must be considered from the beginning. The grading lines and areas for band insertion must be established as the pattern is created and the garment is designed. As a result, these three actions must be completed simultaneously, instead of in linear design process where garment design is completed first, pattern development is completed second, and grading is completed third. These findings support suggestions that the "design and make process has to be transformed in order to create garment designs, both desirable and achievable" in zero-waste [36] (p. 142).

The CZWBG technique had a strong effect on the construction process. The order of operations became significant due to intersecting, matching seams, and seam finishes. Just as zero-waste pattern cutting methods require significant collaboration between the designer and the patternmaker, the CZWBG technique would require collaboration with the construction team.

4.3. Limitations

The aesthetic differences between the graded sizes could be considered a limitation of the method. However, changes between sizes are not an uncommon trait in zero-waste garments. As mentioned previously, designers who have produced zero-waste garments in a range of sizes have mitigated these changes by notifying the customer. Referring back to the zero-waste "woodgrain" dress, Material By Product prepared the customer for aesthetic changes between sizes by stating that "no two sizes are the same" [31] (8:42). If brought to the mass market, brands utilizing the CZWBG technique will also need to notify customers of the differences and educate the customer about the benefits. Additionally, the aesthetic differences are mitigated by the ways in which the method meets industry-standard grading and manufacturing processes. Unlike Holly McQuillan's zero-waste top, which is the same length for all sizes, the CZWBG technique allows for the garments to grade in length as well as girth, creating a superior fit [30].

Another limitation of the study is the additional time which is necessary in production, potentially increasing the garment costs. However, the expenses saved in materials, transportation and the disposal of textile waste will potentially offset this cost. Further

research into the streamlining of the production process could also help lower production times and costs.

The documentation of the design processes presented limitations to the study, as details were forgotten between working on the design and the documentation. The designers noted difficulties documenting as they worked; as such, many waited until the end of their work session or until the end of the project to document their process. As a result, some specific data may not be included in the designer's accounts.

4.4. Further Research

Further research into the CZWBG technique may include a qualitative study to assess whether the aesthetic differences between sizes would be acceptable to consumers. It may also be necessary to explore marketing strategies in order to find the most effective approach to educating the customer and driving sales of garments created using the CZWBG technique. Showing effective sales strategies will encourage designers to adopt the technique and application in mass-market design.

Future iterations of this study will include the creation of additional garment types within each consumer and product category. The continued testing of the method's applicability to various garments will further illuminate the changes necessary to the production process. The six designers involved in this study will develop best practices for garment production using the CZWBG technique. Additionally, it would be highly valuable to estimate the savings of water, emissions, fabric waste, and production time from the utilization of this approach. Researchers should collaborate with fashion industry professionals to determine the potential cost savings for the production of a zero-waste line that utilizes the CZWBG approach.

5. Conclusions

The challenge over the past decade for design scholars experimenting with zero-waste design applications has been to overcome the limitations of the implementation of standardized grading production practices within the mass-market structure. Thus, the intent of this research was to test the efficacy of the CZWBG method, which utilizes bands inserted in strategic locations as a method of grading zero-waste patterns across various consumer categories. Additional purposes were to evaluate the ways in which this grading approach affected the aesthetic outcomes of garments across a size run, and to determine whether this method affected the overall design process of the designers involved.

Through experimental research design, six design scholars successfully tested and incorporated the CZWBG technique in the creation of zero-waste one- or two-piece apparel item(s), subsequently developing three adjacent sizes in an industry-specified size range for their product category. Each design was cut from zero-waste patterns in a mid-range size, and was graded up and down 1–2 sizes using industry-standardized grading. Grading was achieved by varying the widths of strategically inserted bands of fabric or trim.

Based on the designers' aesthetic review of the final design prototypes of each initially constructed size, it was concluded that the design outcomes were highly successful. These designs were perceived as being more marketable than typical zero-waste designs due to the achievement of showing the body's contours. However, the proportions of the garment components differed among the graded sizes. These differences could impact consumer acceptance. Still, it was determined that transparency and the education of the consumer could be an asset as a marketing approach by emphasizing the sustainable aspect of reducing textile waste. As consumers' sustainability awareness and concerns within the fashion industry increase, addressing these issues is worthy of exploration, and could have significant global impacts.

The designers evaluated the manufacturability of the CZWBG technique at a mass level, as it applied to their intended diverse consumer category. They identified and addressed numerous issues while creating the zero-waste marker and during the production phase of the final prototypes. While additional time and production costs were added

during these phases, time was reduced in the cutting phase because the same pattern was utilized for all of the sizes (only the band widths changed). A further production barrier to taking zero-waste designs to the mass production stage is the variation of the construction details to include inconsistencies in the seam allowances. These nuances will also add time and cost to train the technicians in these specifics, and extra steps will be needed to add the banding. Overall, it was determined that the CZWBG method meets industry-standard grading and manufacturing processes, giving zero-waste designs the ability to compete in the mass market domain. Realistically, there are major economic factors that are likely to slow adoption.

The six designers plan future testing of the CZWBG method. The intention is to establish that the CZWBG method applies to a broader offering within the designers' chosen diverse product categories by creating an additional style and developing the three sizes. It will also be worth testing sizes beyond the three sizes to integrate fully a sustainable practice like zero-waste into today's fashion markets. By offering a broader range of sizes, zero-waste garments will better assimilate current apparel assortments in ready-to-wear garments.

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Appendix A

Table A1. Research process documentation.

Research Process Documentation							
Challenge Statement: Goal—Apply Carrico Banded Grading to Garments across Apparel Categories.							
Date Worked	Hours	Project Goals	Achievement	Challenges	Photo 1	Photo 2	Stage # per Lamb & Kallal FEA model [35]

Table A2. Design specifications.

Defined	Reasoning
Fabric Selection and Fiber Content	
Pattern Production Technique	
Fit Choice—highly fitted, moderate fit, loose fit	
Apparel Classification Category	
Garment Type	
Base and Graded Sizes Defined	

Table A3. Zero-waste End Product and Process Evaluation and Narrative.

Zero Waste End Product and Process Evaluation and Narrative	Self Scoring (1-Highly Successful, 5-Unsuccessful)				
	1	2	3	4	5
Perceived Success of Design Concept					
Perceived Success of Pattern Approach					
Perceived Success of Product Aesthetic					
Perceived Success of Product Fit					
Perceived Success of Graded Duplicates					
Perceived Success of Graded Duplicate Aesthetics and Cohesiveness					

Appendix B. Process Assessment Form

Zero Waste Process Assessment Researcher _____

Summary of Preliminary Zero Waste

Challenge March–June 2021

Category _____

Band/Strip Direction

- Straight of grain
 Bias
 Straight of grain and bias

What Worked Well?

Conceptual Stage:

Preliminary Design/Patternmaking/Draping Stage:

Implementation/Construction Stage:

Evaluation Stage (Fit, Functionality, Dressform Applications, Aesthetic Review):

What DID NOT Work Well?

Conceptual Stage:

Preliminary Design/Patternmaking/Draping Stage:

Implementation/Construction Stage:

Evaluation Stage (Fit, Functionality, Dressform Applications, Aesthetic Review):

Perceived Challenges with taking the design to Mass Production

Fabrication:

Patterning/Marker:

Cutting:

Assembly:

Cost:

Documentation Process

Greatest Challenge(s):

Best Strategy(s):

How did the GRADING affect the final Garment appearance across all sizes?

How did the end product differ from Mainstream grading? Is it acceptable? Can it be addressed?

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