

COMPARATIVE ANALYSIS OF DIFFERENT FASHION DRAPING TECHNIQUES ON THE FABRIC UTILIZATION IN THE APPAREL MANUFACTURING INDUSTRY

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Abstract

Draping technique and fabric selection are two of the most influential yet under-quantified variables governing fabric utilization in apparel manufacturing. This study used CLO3D 3D virtual prototyping software to comparatively evaluate the effect of three draping techniques – gathers (by hand, by thread, by elastic), pleats (inverted, cluster, box) and tucks (pin, blind, space) – on fabric efficiency and fabric loss across four dress categories (day wear, party wear, evening wear and experimental wear) and three fabrics (silk, cotton and polyester). Digital 2D patterns and markers were generated for thirty-six garment samples on a standardized female avatar (FV2-02-Feifei-Aforesize), and marker efficiency was recorded as the ratio of pattern area to marker area for a fixed 58-inch marker width. Fabric efficiency ranged from 53.31% (space tuck, party wear) to 97.40% (gathers by hand, experimental wear), with pleats – particularly the inverted pleat – showing the most consistent efficiency across dress styles (85.43–89.67%), while tuck techniques showed the widest variability (53.31–90.04%). Two-way analysis of variance indicated that draping technique, dress style, and their interaction were all significant sources of variation in both fabric efficiency and fabric wastage. These findings suggest that draping-technique selection at the design stage has a measurable, and in several cases larger, effect on material efficiency than fabric type alone, and that CLO3D-based virtual marker trialing can identify high-waste technique/style combinations before physical sampling begins, supporting more sustainable and cost-effective apparel production decisions.

1. INTRODUCTION

The global apparel industry consumes vast quantities of textile raw material every year, and a substantial share of that material never becomes part of a finished garment. Conventional cut-and-sew marker planning typically achieves fabric utilization of only around 85%, meaning that roughly 15% of every fabric roll is lost as cutting-room waste before a garment is even sewn (Enes &

Kipöz, 2020). This pre-consumer waste carries a direct economic cost, since fabric is usually the largest single component of garment cost, and a direct environmental cost, since textile production is among the more resource- and emission-intensive manufacturing sectors. Reducing this waste at the design and pattern-cutting stage – rather than only at the recycling stage – has therefore become a central concern of sustainable

fashion research (Sawhney, 2023; ElShishtawy, Sinha, & Bennell, 2022; Rissanen, 2008).

Draping is one of the oldest methods of garment construction, and it remains central to how designers introduce fullness, shape and movement into a garment through techniques such as darts, ease, gathers, pleats, shirring and tucks. Each technique manages excess fabric differently: gathers compress fullness along a stitched line, pleats fold fabric back on itself in regular or irregular formations, and tucks stitch a controlled fold for a more restrained, decorative fullness. Because each technique produces pattern pieces of different shape, size and quantity, the choice of draping technique should, in principle, influence how efficiently those pieces can be nested on a fabric marker – yet this relationship has received comparatively little quantitative attention in the literature, which has tended to focus either on marker-planning algorithms in isolation (ElShishtawy et al., 2022) or on zero-waste geometric pattern design (Rissanen, 2008; Sawhney, 2023) rather than on conventional draping techniques themselves.

The emergence of 3D virtual prototyping software such as CLO3D has made it practical to test this relationship at scale without cutting physical fabric. CLO3D simulates fabric behavior on a virtual avatar using physics-based models of bending, shear, stretch and weight, and its marker-making module reports pattern count, marker length and fabric efficiency directly, allowing designers to compare technique and fabric combinations digitally before committing to physical samples (Habib & Alam, 2023). Independent validation studies have shown that CLO3D's simulated drape behavior corresponds closely, though not perfectly, with the drape of the corresponding physical fabric (Ashmawi, Hassouna, Nasr Eldine, & El-Newashy, 2021), which supports its use as a design and screening tool ahead of physical sampling.

This study uses CLO3D to comparatively evaluate three draping technique families – gathers, pleats and tucks, each represented by three sub-types – across four dress categories (day wear, party wear, evening wear and experimental wear) and three fabrics with contrasting mechanical properties

(silk, cotton and polyester). The specific objectives are to (i) quantify fabric efficiency and fabric loss for each technique/sub-type and dress style combination, (ii) identify which draping techniques are most and least fabric-efficient, and whether this ranking is stable across dress styles, and (iii) statistically test whether draping technique, dress style, and their interaction are significant predictors of fabric efficiency and wastage. The resulting comparative dataset is intended to give designers and pattern makers an evidence base for selecting draping techniques that balance aesthetic intent with material efficiency.

2. Experimental Work

2.1. Selection of Tools and Equipment

2D patterns, markers, and simulation of 3D garments were created on virtual model in real-time through CLO3D software, thus enhancing both the aesthetic and functional aspects of the selected garments. CLO3D marker-making method was further tweaked to optimize the fabric efficiency for the clothing development. This approach greatly reduces material waste in clothing design, which not only minimizes physical sampling but also supports the goals of sustainable fashion production. Similarly, digital fashion illustrations and croquis were constructed through the Adobe Photoshop. Moreover, graphic tablet was used for the creation of precise drawing and design refinements. MS Excel was used for organizing the data and conducting preliminary calculations. Statistical analysis was conducted through R Studio for ANOVA test results.

2.2. Selection of Fabrics

Three types of fabrics, i.e., silk, cotton and polyester were selected to analyse the draping effect on the same avatar. The color of all the fabrics was kept white in order to get a crisp and clear visual aspect of draping. The detailed characteristics of the fabrics are enlisted in the Table 1. These fabrics were evaluated through drape affect using using 3D CLO software to examine various fabrics performance under different draping techniques.

Table 1. Selection of Fabrics and their Characteristics

Sr.#	Fabric Types	Fabric Characteristics	Thickness (mm)	Weight (g/m ²)
1	Silk	Stretch Weft (63), Stretch Warp (40), Shear (35), Bending Weft (55), Bending Warp (14), Bending Bias (38), Internal Damping (1), Density (5), Friction (3)	0.16	
2	Cotton	Stretch Weft (27), Stretch Warp (27), Shear (9), Bending Weft (10), Bending Warp (20), Bending Bias (11), Density (27), Friction (3)	0.5	
3	Polyester	Stretch Weft (58), Stretch Warp (59), Shear (57), Bending Weft (49), Bending Warp (36), Bending Bias (47), Buckling Stiffness Weft (25), Buckling Stiffness Warp (25), Internal Damping (1), Density (11), Friction (3)	0.2	135.859

2.3. Selection of Avatar and it's Key Body Measures

Table 2 shows the FV2-02-Feifei-Aforsize Avatar derived through the CLO3D software. The measurements of avatar and manikin (in the design studio of the university), were similar to

each other. The pose of the female avatar has moderate arm openings, specifically beneficial for designing casual wear and active wear, where ease of movement is essential and stylistic goals of the apparel line created were critical component in the simulation and design process.

Table 2. Key measurements of the Avatar (FV2-02-Feifei- Aforsize)

Sr. Avatar Parts		Female Body Measurements	
#			
1	Total Body	Height	Total Height 175.26 cm
		Width	Bust/Chest 80.64 cm
			Circumference
2	Neck	Neck base	Circumference 35.56 cm
		High hip	Circumference 80.33 cm
		Low hip	Circumference 95.57 cm
3	Shoulder	Across Shoulder	Curvilinear 37.78 cm
4	Leg	Inseam	Height 84.14 cm
		Thigh	Circumference 54.93 cm
5	CF neck to waist	CF neck to waist	33.97 cm
6	CB neck to waist	CB neck to waist	38.10 cm

7	Arm	CB neck to wrist	Circumference	77.19 cm
		Bicep		25.40 cm
		Hand		16.10 cm
		Total Rise		72.39 cm
8	Extra Measurements	Head		54.40 cm
9	Apex	HPS to apex		25.08cm



Selection of Avatar (FV2-02-Feifei- Aforsize)

2.4. Selection of Draping Techniques

In the garment construction, draping is the oldest method to fit clothing around the body without using patterns. Moreover, it allows the designers to move beyond traditional sketches, giving them the freedom to experiment, apply different draping techniques and innovate the perfect fit for different body types. These draping techniques include darts, ease, gathers, pleats, shirring and tucks. Darts serve the purpose of contouring fabric to conform to the body's shape, enhancing the natural curves by providing fullness. Easing is employed across various pattern pieces and garment constructions showing how additional

space is incorporated for comfort and movement. Gathers represent visible fullness intentionally integrated into the garment's design for both functional and decorative purposes. Pleats align with the grain manage fullness within garment design with varying softness or crispness. Shirring is the creation of parallel and uniform gathered rows through stitching, often used decoratively on lightweight fabrics. Tuck is stitching a fold of fabric, primarily for decorative purposes but can shape fabric to the body. Table 3 shows the selected draping techniques used in the construction of four styles of dresses.

Table 3. Selection of draping techniques for dresses

Techniques	Sub Types of Drapes	Selected Types of Drapes
Gathers	Gather by Hand, Gather with Thread, Gatherwith Elastic RegularGather by Hand, Gather with Thread, Gather with Elastic	Gather by Hand, Gather with Thread, Gather with Elastic
Pleats	Gathers, Distributed Gathers, Pleated Gathers, Circular Gathers, Zone Gathers	Box pleats, Inverted pleats, Cluster pleats
Tucks	Box Pleats, Inverted Pleats, Cluster Pleats, Accordion Pleats, KnifeBox or Side Pleats	Pin Tuck, Spaced tuck, Blind Tuck

2.5. Construction of Fashion Croqui, Drawing and Illustration

Figure 1 has shown the specific pose of croqui that adapt style, silhouette, and movement characteristics of dresses. The croqui was drawn through Adobe Photoshop, and the pose was considered standard as it provides a unique features (thorough understanding) of the fabrics/dresses visually on the body (an interaction between a dress and a body). Fashion drawings, either executed through traditional techniques or contemporary digital methods, provides a primary means of visualizing and expression of design ideas. It helps to analyse various styles, materials, and embellishments to refine the concepts before

producing an actual garments (bringing creative visions to life in the form of tangible fashion pieces). Fashion illustration provides a foundational insight of the garment's aesthetic appeal which serves as a conceptual blueprint, outlining the primary visual characteristics and facilitating in volume and shape of the garment. This underscores the craftsmanship involved as well the versatility in design techniques employed to achieve the desired aesthetic outcome. This illustration is crafted using Adobe Photoshop, a tool pivotal for delineating the stylistic elements of the garment effectively. Figure also describes the fashion illustration of four dress styles (day wear, party wear, evening wear and experimental wear).



Figure 1. Croqui with fashion drawing and illustration with four dresses (day wear, party wear, evening wear and experimental wear)

2.6. Selection of Dresses

Four dresses, i.e., day wear, evening wear, party wear, and experimental were selected for the experimental design. Daywear includes dresses designed for everyday activities and casual settings that blend functionality with aesthetic appeal, utilizing materials that are durable yet comfortable, suitable for various daily tasks from professional to leisure contexts. Evening wear are elegance and luxury, crafted from high-quality materials such as silk, satin, or velvet, and often decorated with elaborate details like lace, sequins, and embroidery to convey a sense of sophistication and grandeur. Party wear are designed for social and celebratory events. They are characterized by their vivid colors and unique patterns, crafted not only to draw attention but also to ensure practicality, allowing for ease of movement during

social interactions and dance. Experimental dress seeks the conventional paradigms of fashion by employing non-traditional designs and materials. They serve as a testament to avant-garde fashion, in fabric treatment and garment structure, thereby expanding the boundaries of traditional dressmaking.

2.7. Creation of Garment Samples

2.7.1. Development of Dresses through Gathers Draping Technique

Gather draping technique was chosen to enhance the garment's texture and form. Three specific types of gathers were considered, i.e., fashioned by thread, fashioned by hand, and formation with elastic. Each method offers distinct qualities and effects, allowing for a diverse exploration of volume and shape within the garment. This

approach not only underscores the craftsmanship involved but also highlights the versatility in design techniques employed to achieve the desired aesthetic outcome. Figure 2 has shown the fashion

drawing and fashion illustration of four dresses with gathers by hand, gathers by thread and gathers by elastic.

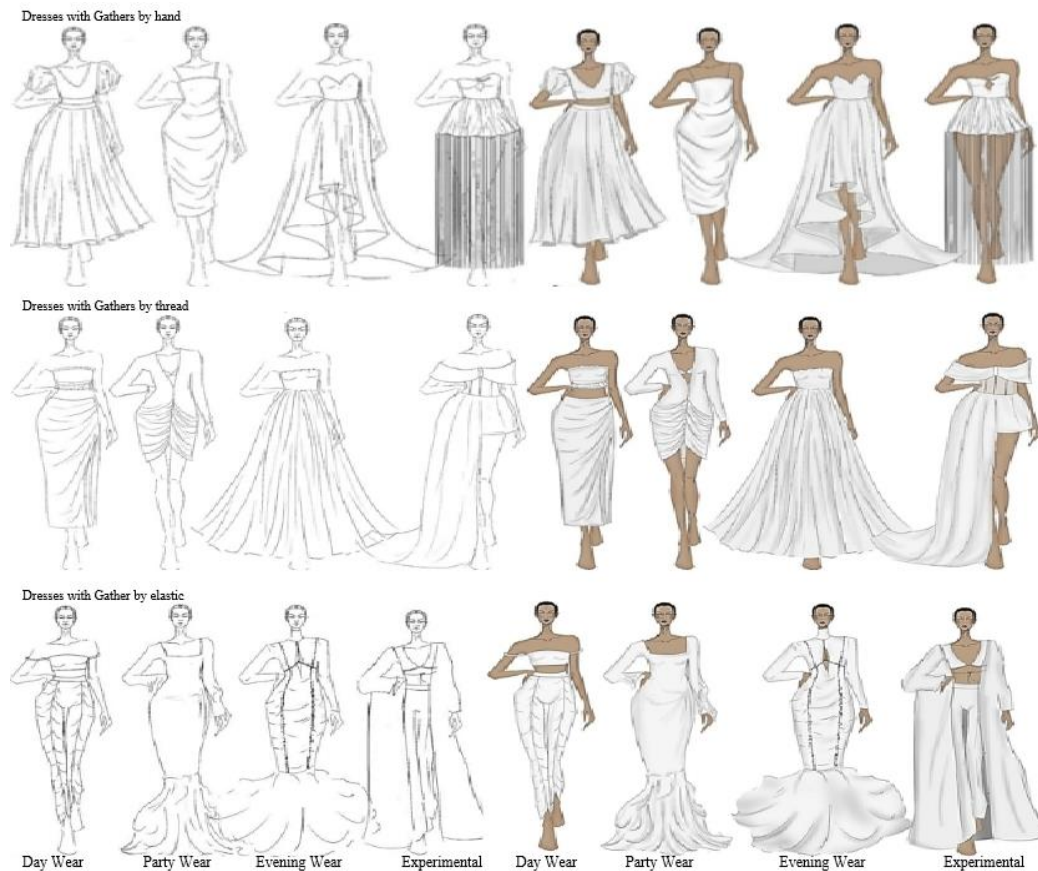


Figure 2. Fashion drawing and illustration of four dresses with gathers and its types

2.7.2. Development of Dresses through Pleats Draping Technique

Pleat's primary significance lies in its ability to add texture, movement, and volume/fullness to the cloth/garment to allow freedom of movement or combining aesthetic appeal with functional design. They can be sewn or left unstitched, folded and pressed or unpressed. They can be arranged in even or uneven groups. Pleat depth can be one, two, or three times deeper. Three specific types of

pleats were considered, i.e., inverted, cluster and box. Each type offers distinct effects for a diverse exploration of fullness and shape of the garment. This technique dominating heavier in colder apparels and lighter, flowy pleats for spring and summer apparel collections thus achieving the desired aesthetic outcome. Figure 3 has shown the fashion drawing and fashion illustration of four dresses with.

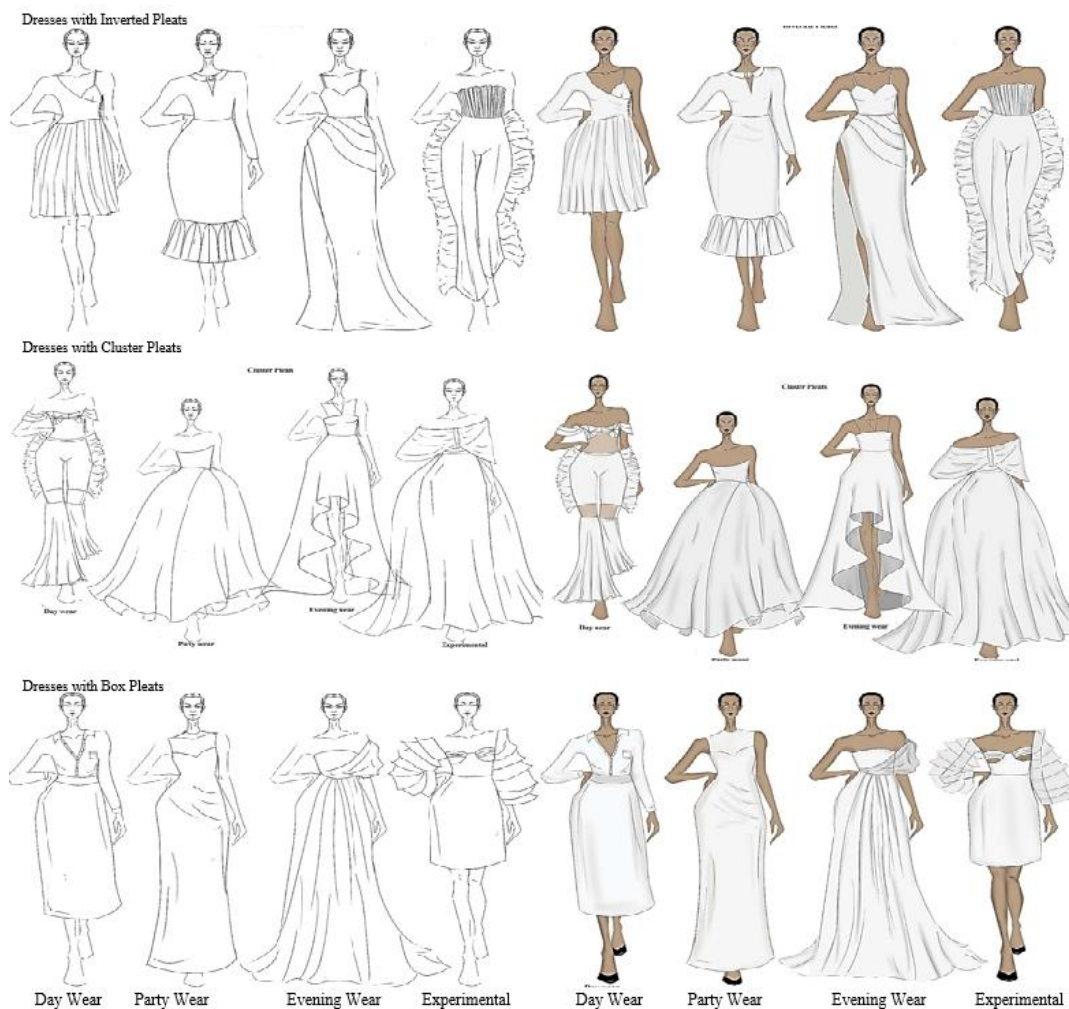


Figure 3. Fashion drawing and illustration of four dresses with pleats and its types

2.7.3. Development of Dresses through Tuck Draping Technique

Tucks in garments are basically crafted folds in fabric achieved through stitching, serving both decorative and shaping functions in the realm of garment construction. Whether executed as a straight or angled fold, its primary purpose is to introduce visual interest texture (aesthetic finesse and tailored elegance) or contribute to the overall

fullness. Tucks can be horizontal, vertical and diagonal, and may differ in width or height. Three types of tucks were considered, i.e., blind tuck, space tuck and pin tuck. Each type offers unique design possibilities and creative opportunities to elevate your garments. Figure 4 has shown the fashion illustration of dresses with three different types of tucks in four styles of dresses.

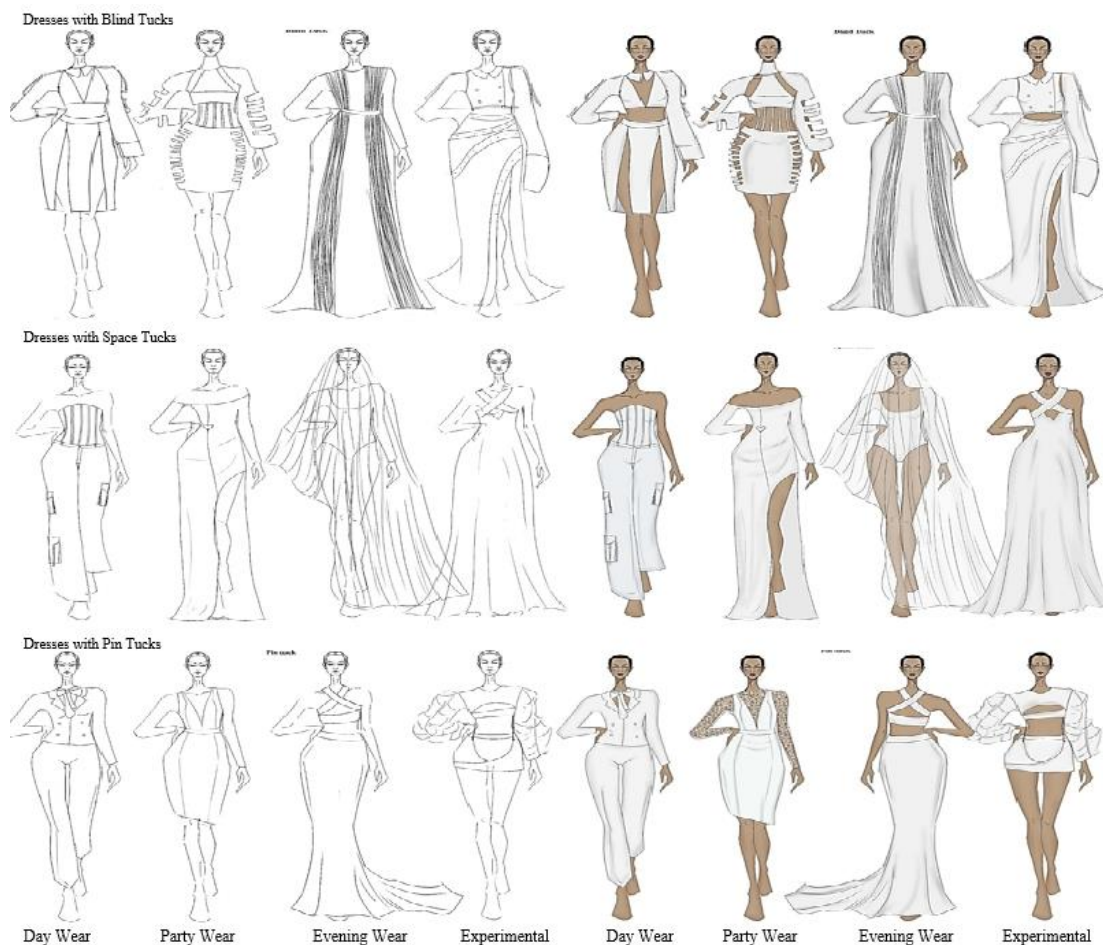


Figure 4. Fashion drawing and illustration of four dresses with tucks and its types

2.8. 3D Simulation and rendering in CLO3D

3D simulation in CLO3D is a transformative technology that enhances the transition from conceptual design to tangible product. It enables to create detailed 3D models from 2D patterns, utilizing advanced algorithms to simulate realistic fabric behavior and garment dynamics on virtual avatars thus assisting in rapid prototyping, immediate visualization of design alterations, and efficient decision-making for garment's drape, fit,

and movement. This accelerates the design process, fosters creativity, and reduces the need for physical samples. Similarly, rendering in CLO 3D, creates accurate and visually appealing images of their 3D garment simulations. This feature leverages sophisticated shading, lighting, and texturing technologies to realistically depict how fabrics behave in various settings, offering a true-to-life view of the final garments.

Table 4. Day wear Dresses with gathers, pleats and tucks

Cotton Fabric		Polyester Fabric		Silk Fabric	
1. Day Wear Dresses with Gathers by Hand					
					
2. Day Wear Dresses with Gathers by thread					
					
3. Day Wear Dresses with Gathers by Elastic					
					
4. Day Wear Dresses with inverted pleats					
					
5. Day Wear Dresses with cluster pleats					
					
6. Day Wear Dresses with box pleats					
					
7. Day Wear Dresses with pin tuck					
					
8. Day Wear Dresses with blind tuck					
					
9. Day Wear Dresses with space tuck					



The rendering function also streamlines decision-making and marketing processes, allowing to generate promotional content directly from their simulations. This ensures that the visual materials align closely with the actual products, improving efficiency and communication with customers and stakeholders. Table 4, Table 5, Table 6, Table 7,

Table 8, Table 9, Table 10, Table 11, and Table 12 provides an overview of the 3D simulation and rendering of 36 dresses developed through CLO3D. These fashion avatar models with dresses in the tables are in the continuity of the figures expressed earlier in the experimental design.

Table 5. Party wear Dresses with gathers, pleats and tucks

Cotton Fabric		Polyester Fabric		Silk Fabric	
Party Wear Dresses with Gathers by Hand					
					
Party Wear Dresses with Gathers by thread					
					
Part Wear Dresses with Gathers by Elastic					
					
Party Wear Dresses with inverted pleats					
					
Party Wear Dress with Cluster Pleat					
					

Party Wear Dress with Box Pleat					
					
Party Wear Dress with Pin Tuck					
					
Party Wear Dress with Blind Tucks					
					
Party Wear Dress with Space Tucks					
					

Table 6. Evening wear Dresses with gathers, pleats and tucks

Cotton Fabric		Polyester Fabric		Silk Fabric	
Evening Wear Dresses with Gathers by thread					
					
Evening Wear Dresses with Gathers by thread					
Evening Wear Dresses with Gathers by elastic					
					

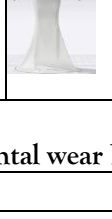
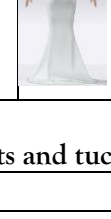
Evening Wear Dress with inverted pleat					
					
Evening Wear Dress with Cluster Pleat					
					
Evening Wear Dress with Box Pleat					
					
Evening Wear Dress with Pin Tuck					
					
Evening Wear Dress with Blind Tucks					
					
Evening Wear Dress with Space Tucks					
					

Table 7. Experimental wear Dresses with gathers, pleats and tucks

Cotton Fabric	Polyester Fabric	Silk Fabric
Experimental Wear Dresses with Gathers by Hand		
Experimental Wear Dresses with Gathers by thread		



Experimental Dresses with Gathers by elastic



Experimental Wear Dress with inverted pleat



Experimental Dress with Cluster Pleat



Experimental Dress with Box Pleat

**Experimental Dress with Pin Tuck****Experimental Dress with Blind Tucks****Experimental Dress with Space Tucks**

3. Results and discussions

Thirty-six dresses were accumulated by using three different types of draping techniques, i.e., gathers (gathers by hand, gathers by thread and gathers with elastic), pleats (inverted, cluster and box) and tucks (pin, blind and space) with four different dress styles (day wear, party wear, evening wear, experimental wear) in order to evaluate the

influence of aesthetic appeal and the fabric utilization/ fabric efficiency. Three types of fabrics, i.e., silk, cotton and polyester were utilized on which pattern markers were constructed. The results were observed through the factors including fabric consumption (fabric length / marker length), fabric efficiency (area of the fabric used for garment component parts), fabric loss

(parts of the fabric not utilized in the garment components) and cost-effectiveness. Figure X summarize the development of 36 samples.

3.1. Comparative Results of Fabric Efficiency in Day Wear Dresses with gathers, pleats and tucks

Figure 5 has shown day wear dresses with gathers, pleats and tucks. Pattern markers contained five garments each, created using a 2-way grain direction, with an initial target efficiency of 100%. Width of the all the pattern markers was kept constant, i.e., 58 inches. 125 pattern pieces of dresses with gathers by hand, were arranged in 32.65 meters marker length. 69.81% fabric efficiency was achieved with 30.19% fabric loss. Similarly, day wear dresses by thread, 115 pieces were arranged in 3.36 meters marker length while achieving 83.22% fabric efficiency with 16.78% losses. Lastly, day wear dresses with gathers by elastic, 35 pattern pieces were organized in 5.78 meters marker and attained 78.40% fabric efficiency with 21.60% losses.

115 pattern pieces of day wear dresses with inverted pleats were arranged in 7.03 meters marker length and achieved 88.87% fabric efficiency with 11.13% losses. Similarly, dresses with cluster pleats, 105 pattern pieces were placed in 13.13 meters marker length which lead to 58.76% fabric efficiency and 41.24% losses. Lastly, dresses with box pleats, 60 pattern pieces were organized in 10.88 meters marker length and achieved 92.78% fabric efficiency and 7.22% losses.

100 pattern pieces of day wear dresses with pin tucks were arranged in 7.84 meters marker length and attained 81.31% fabric efficiency with 18.69% wastage. Similarly, 170 pattern pieces were placed in 4.89 meters marker length that achieved 90.04% fabric efficiency and 9.96% losses. Lastly, 125 pattern pieces were arranged in 6.73 meters marker length and attained 87.35% fabric efficiency with 12.65% losses.





Figure 5. Day wear dresses with gathers, pleats and tucks with their pattern markers

Figure 6 has shown the comparative results of fabric efficiency across all nine gather, pleat and tuck sub-types used in day wear dresses. Box pleats achieved the highest fabric efficiency (92.78%), followed closely by inverted pleats (88.87%) and blind tucks (90.04%), while cluster pleats recorded

the lowest efficiency (58.76%) and the highest fabric loss of any day wear sub-type (41.24%). Gathers produced a relatively narrow, mid-range efficiency band (69.81–83.22%) irrespective of sub-type.

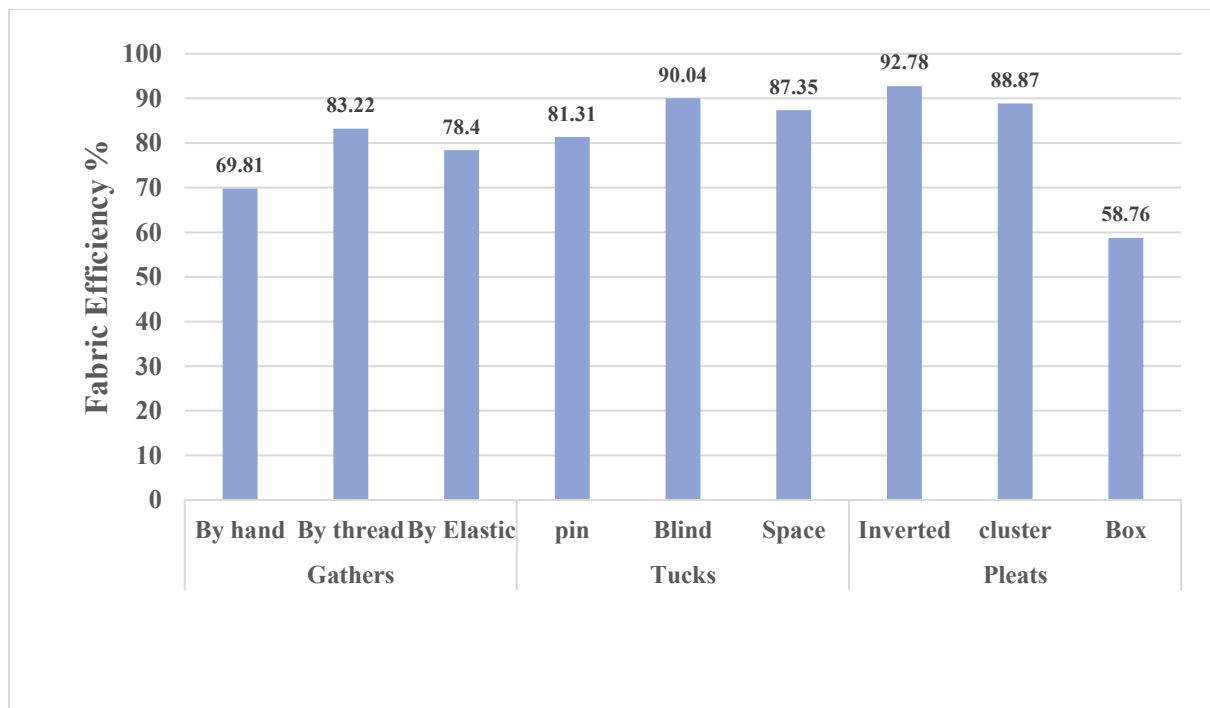
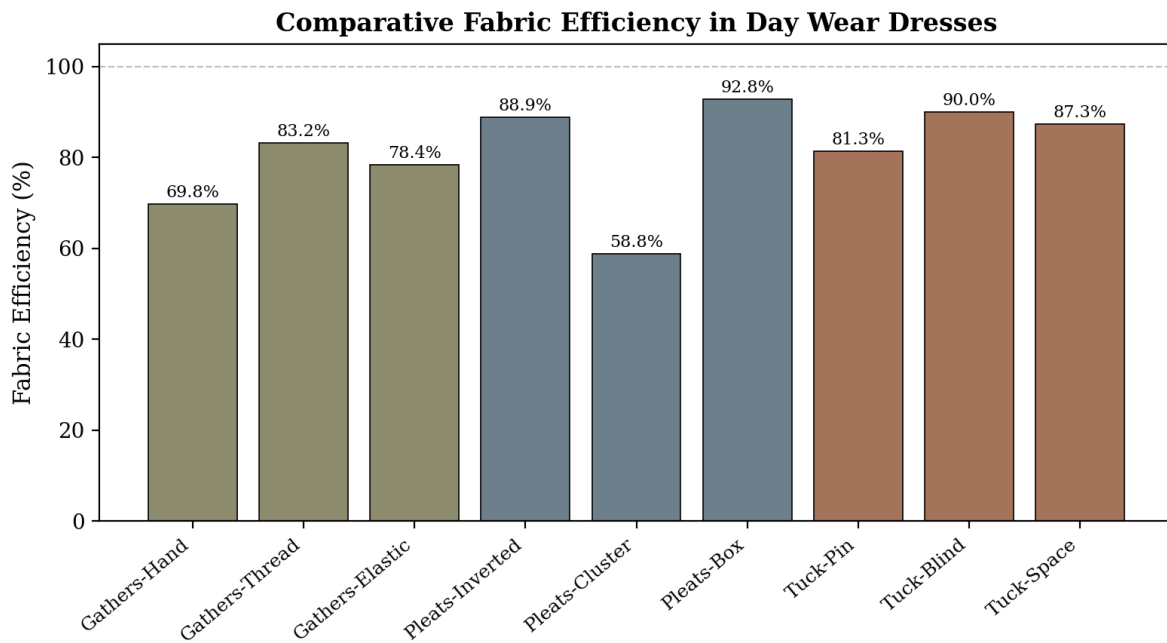


Figure 6. Comparative results of fabric efficiency in day wear dresses

3.2. Comparative Results of Fabric Efficiency in Party Wear Dresses with gathers, pleats and tucks
Figure 7 illustrated the CLO 3D pattern markers for a party wear dresses with gathers, pleats and

tucks, pattern markers contained five garments each, created using a 2-way grain direction, with an initial target efficiency of 100%. In the dresses with gathers by hand, 80 pattern pieces were

arranged in a 5.07 meters marker length with a 74.17% fabric efficiency and 25.83% wastage. In the dresses with gathers by thread, 95 pattern pieces were placed in a 3.99 meters marker length. 72.91% fabric efficiency was achieved with a 27.09% wastage. Likewise, in the dresses with gathers by elastic, a total of 125 pattern pieces were ordered in a 9.91 meters marker length with a 74.23% fabric efficiency (25.77% wastage).

75 pattern pieces of dresses with inverted pleats were laid in a 32.65 meters marker length with 89.67% fabric efficiency 10.33% wastage. Party wear dresses with cluster pleats, 55 pattern pieces were placed in a marker length of 42.32 meters. 68.77% fabric efficiency was achieved with 31.23% wastage. Likewise, dresses with box pleats, 45 pattern pieces were arranged in 7.87 meters marker length thus achieving 76.92% fabric efficiency and 23.08% wastage.



Party wear Dresses with gather by hand, by thread and by elastic with their pattern markers



Party wear dresses with pleats inverted, cluster and box with their pattern markers



Party wear dresses with tucks by pin, by blind and by space with their pattern markers



Figure 7. Party wear dresses by hand, by thread and by elastic with their pattern markers

40 pattern pieces of pin tuck party wear dresses were arranged in a 2.62 meters marker length having 88.48% fabric efficiency and 11.52% wastage. 110 pattern pieces of blind tuck dresses were placed in a 7.19 meters marker length leading

with 86.20% fabric efficiency and 13.80% wastage. Lastly, 45 pattern pieces of space tuck dresses were laid in a 6.73 meters marker length with 53.31% fabric efficiency and 46.69% wastage.

Figure 8 has shown the comparative results of fabric efficiency across gather, pleat and tuck sub-types used in party wear dresses. Inverted pleats produced the highest fabric efficiency (89.67%), followed by pin tucks (88.48%) and blind tucks (86.20%). Space tucks recorded the lowest

efficiency of any party wear sub-type (53.31%, with 46.69% fabric loss), and cluster pleats were similarly inefficient (68.77%). Gathers again clustered in a mid-range band (72.91–74.23%) regardless of the gathering method used.

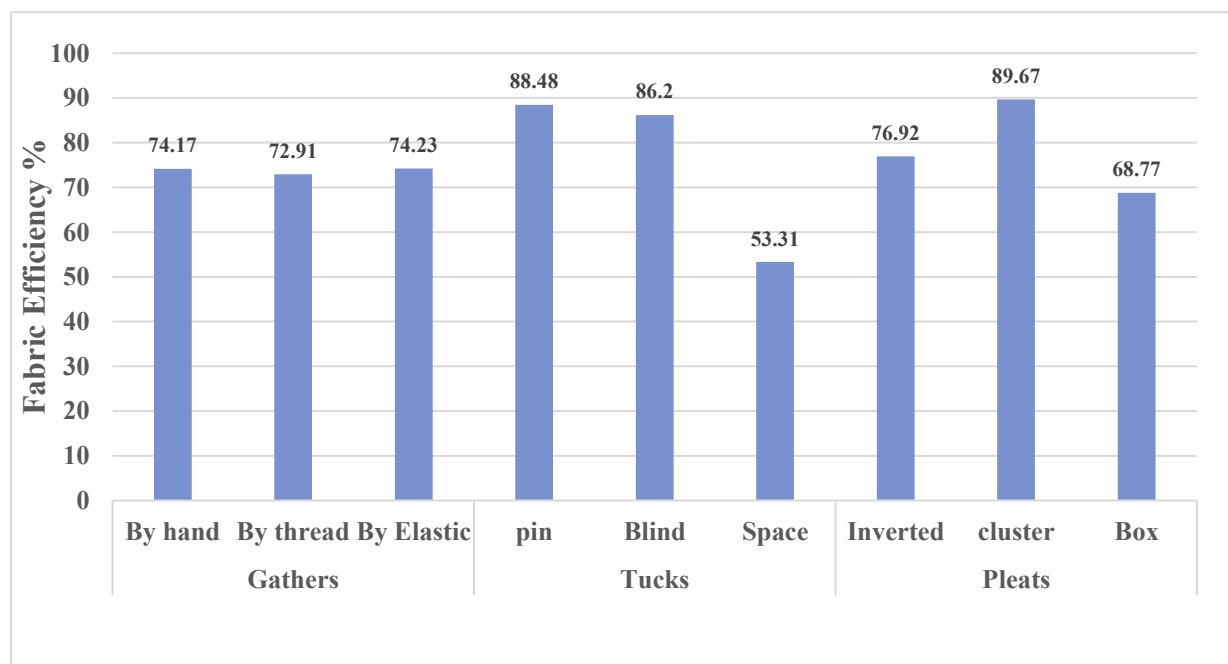
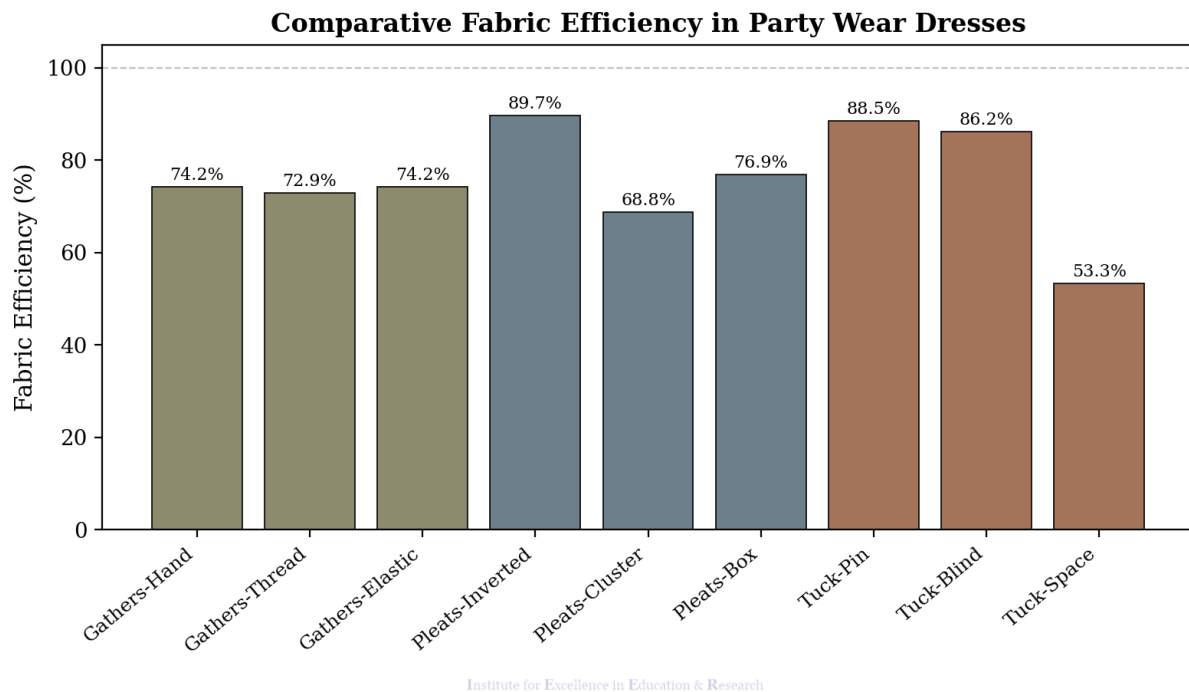


Figure 8. Comparative results of fabric efficiency in party wear dresses

3.3. Comparative Results of fabric efficiency in evening wear dresses with gathers, pleats and tucks

Figure 9 illustrated pattern markers for an evening wear dresses with gathers, pleats and tucks draping techniques. Markers of five garments were created using a 2-way grain direction, with an initial target efficiency of 100%. In the dresses with gathers by hand, 70 pattern pieces were organized in a marker length of 24.65 meters thus leading to 75.92% fabric efficiency having 24.08% wastage. In the dresses of gathers by thread, 115 pattern pieces were laid in a marker length of 42.04 meters. 80.52% fabric efficiency was achieved which resulted with 19.48% wastage. In the dresses with

gathers by elastic, 235 pattern pieces were placed in a marker length of 21.63 meters achieving 73.93% fabric efficiency 26.07% wastage.

Evening wear dresses with inverted pleats, 50 pattern pieces were organized in a 5.40 meters marker length and achieved 89.66% fabric efficiency (10.34% wastage). Dresses with cluster pleats, 45 pattern pieces were arranged in a 10.75 meters marker and attained 82.53% fabric efficiency with the 17.47% wastage. Like wise, 60 pattern pieces of dresses with box pleats, were laid in a marker length of 35.36 meters and lead to achieve 86.63% fabric efficiency with 13.37% wastage.





Figure 9. Evening wear dresses with pleats inverted, cluster and box with their pattern markers

Evening wear dresses with pin tucks, 35 pattern pieces were laid in a 10.86 meters marker length. 57.20% fabric efficiency was attained with the 42.20% fabric wastage. Dresses with blind tucks, 90 pattern pieces were placed in a 27.47 meters marker length thus leading to 86.75% fabric efficiency and 13.05% fabric wastage. Lastly,

evening wear dresses with space tucks, 15 pattern pieces were organized in a 6.73 meters marker length, thus attained 62.52% fabric efficiency. Figure 10 has shown the comparative results of fabric efficiency for evening wear dresses. Inverted pleats (89.66%) and box pleats (86.63%) were the most fabric-efficient sub-types, and blind tucks

performed almost as well (86.75%). Pin tucks were markedly less efficient than the other evening wear sub-types (57.20%, with 42.80% fabric loss), and space tucks were also comparatively weak

(62.52%). Gathers by thread (80.52%) outperformed gathers by hand (75.92%) and by elastic (73.93%) in this dress category.

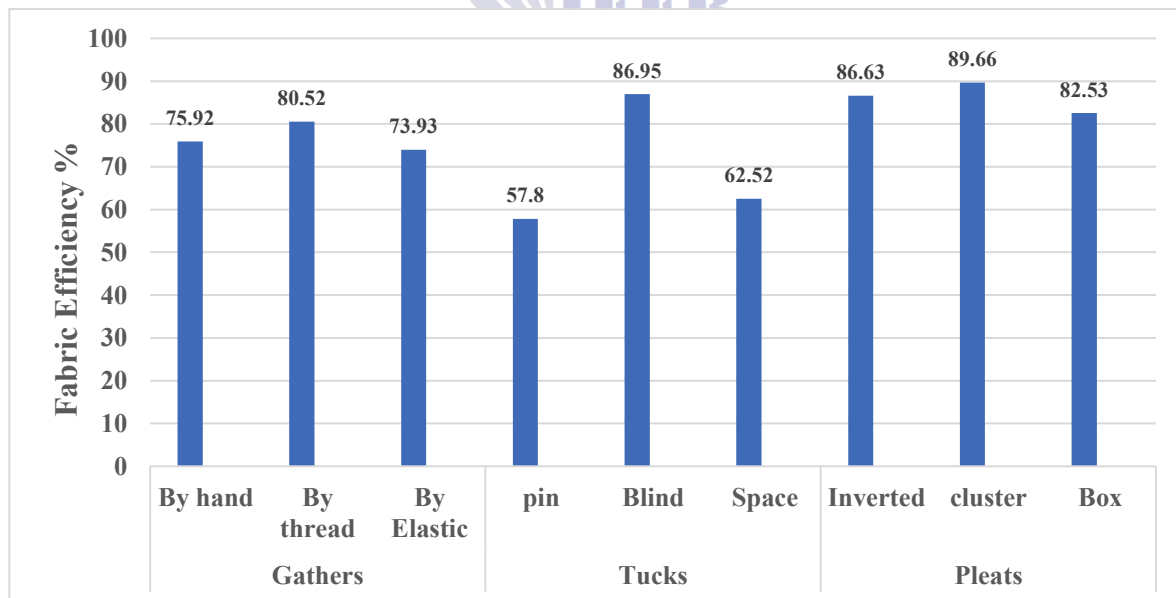
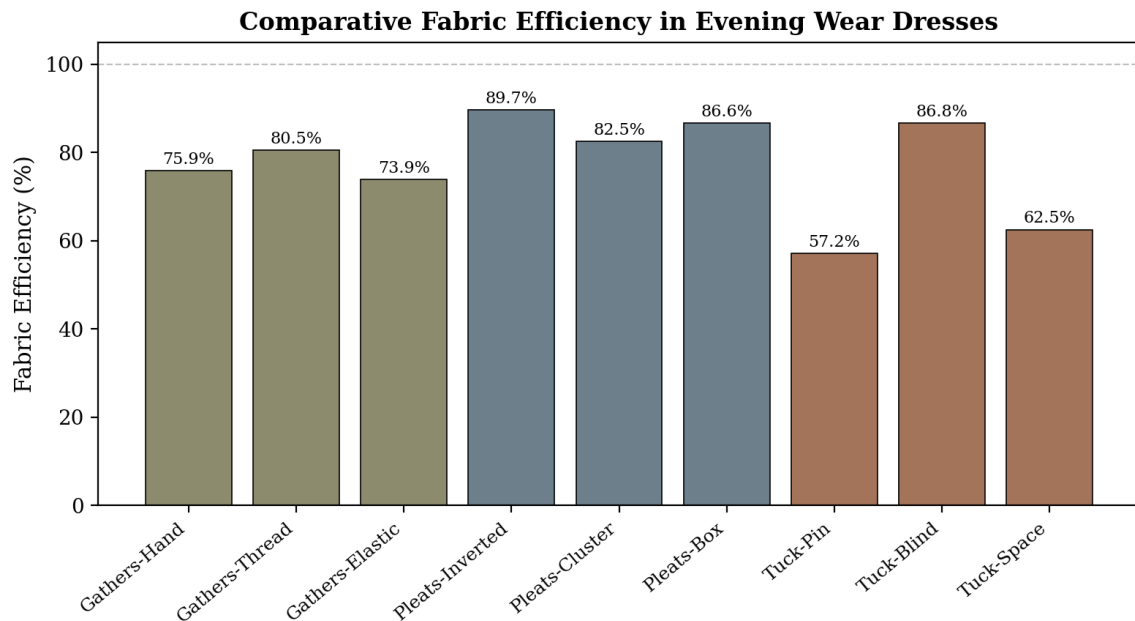


Figure 10. Comparative results of Fabric Efficiency in Evening Wear

3.4. Comparative results of fabric efficiency in experimental wear dresses with gathers, pleats and tucks

Figure 11 illustrated pattern markers for an experimental wear dresses with gathers, pleats and tucks draping techniques. Markers of five garments were created using a 2-way grain

direction, with a target efficiency of 100%. Experimental dresses with gathers by hand, 95 pattern pieces were arranged in a marker length of 6.69 meters and attained 97.40% fabric efficiency with a 2.60% fabric wastage. While, experimental dresses with gather by thread, 250 pattern pieces were arranged in a marker length of 8.93 meters.

It lead to 75.07% fabric efficiency with a fabric wastage of 24.93%. Likewise, experimental wear dress with gathers by elastic, 175 pattern pieces were arranged in a marker length of 31.86 meters. The fabric efficiency achieved was 83.41% leading to 16.59% fabric wastage.





Figure 11. Experimental wear dresses with pleats inverted, cluster and box with their pattern markers

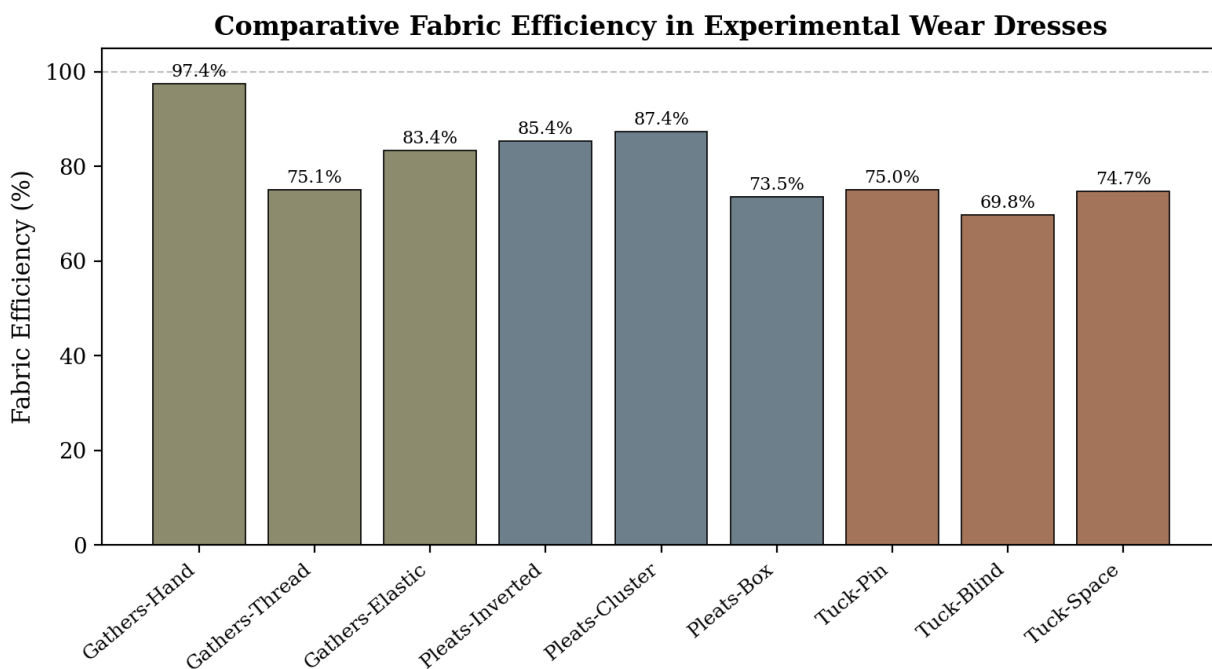
Experimental dresses with inverted pleats, 80 pattern pieces were arranged in a marker length of 14.04 meters and attained the fabric efficiency 85.43% leading to 14.57% wastage. Experimental

dresses with cluster pleats, 75 pattern pieces were arranged in a marker length of 13.22 meters with fabric efficiency of 87.39% and 12.61% wastage. Similarly, experimental dress with box pleats, 40

pattern pieces were arranged in a marker length of 16.27 meters leading to an actual efficiency of 73.53% and 26.47% wastage.

Experimental wear dresses with pin tuck, 130 pattern pieces were arranged in a marker length of 7.55 meters and attained fabric efficiency 75% while leading to a 25% wastage. Experimental dresses with blind tucks, 110 pattern pieces were arranged in a marker length of 11.02 meters thus achieving the fabric efficiency 69.81% with 30.19% wastage. Lastly, experimental wear dresses with space tucks, 40 pattern pieces were arranged in a marker length of 7.56 meters. It lead to fabric efficiency of 74.68% (25.32% wastage).

Figure 12 has shown the comparative results of fabric efficiency for experimental wear dresses. Gathers by hand achieved the highest fabric efficiency recorded across the entire study (97.40%, with only 2.60% fabric loss), while blind tucks were the least efficient sub-type in this category (69.81%). Cluster pleats (87.39%) and inverted pleats (85.43%) performed consistently well, reinforcing the pattern seen in the other three dress categories that pleated techniques tend to nest more predictably than gathered or tucked panels, with the notable exception of hand-gathered experimental wear panels.



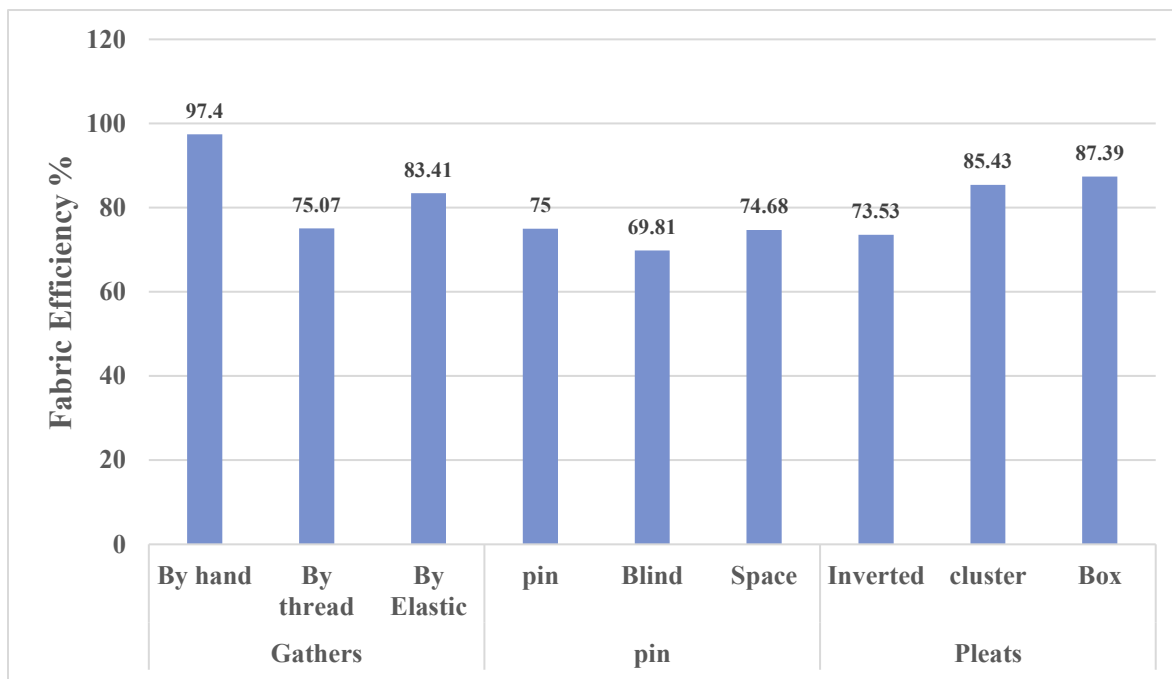


Figure 12. Comparative results of fabric efficiency in experimental wear

3.5. Comparative results of fabric efficiency in dress wear with gathers draping technique

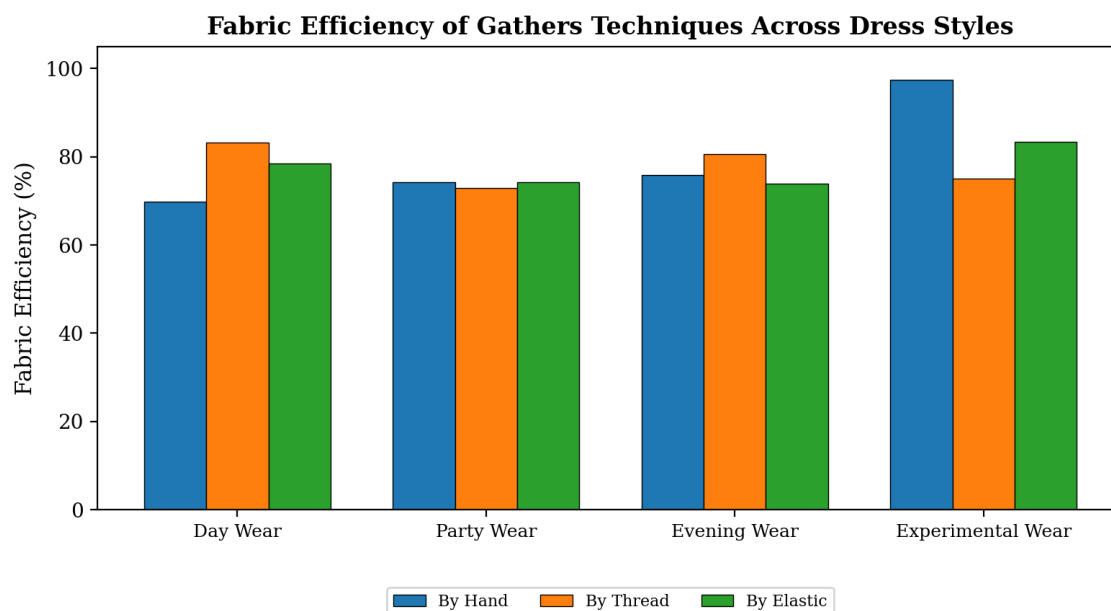


Figure 13. Day wear with gathers, evening wear gathers, party wear gathers and experimental wear gathers.

Across all four dress categories, gathers by hand and gathers by thread produced fairly comparable

efficiency in day, party and evening wear (70–83%), but gathers by hand rose sharply to 97.40%

in experimental wear – the single highest efficiency value recorded in the entire study. Gathers by elastic remained the most stable of the three sub-types, staying within a narrow 73–84%

band regardless of dress style, suggesting that elastic-formed gathers are the least sensitive to overall garment silhouette.

3.6. Comparative results of fabric efficiency in dress wear with pleats draping technique

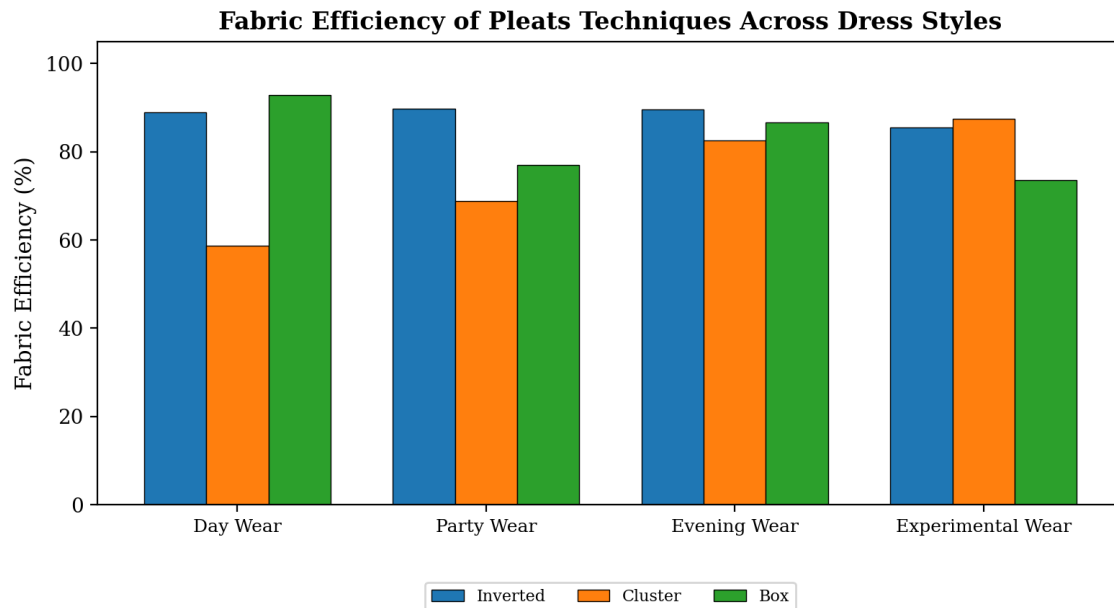


Figure 14 Day wear with gathers, evening wear gathers, party wear gathers and experimental wear gathers.

Pleats were the most consistently fabric-efficient technique family across dress styles. Inverted pleats stayed within a tight 85.43–89.67% band across all four dress categories, making it the most predictable sub-type in the entire study. Cluster pleats were the exception: efficient in

experimental wear (87.39%) but the least efficient sub-type in day wear (58.76%), indicating that cluster-pleat efficiency is strongly dependent on overall garment silhouette rather than being an intrinsic property of the technique.

3.7. Comparative results of fabric efficiency in dress wear with tuck draping technique

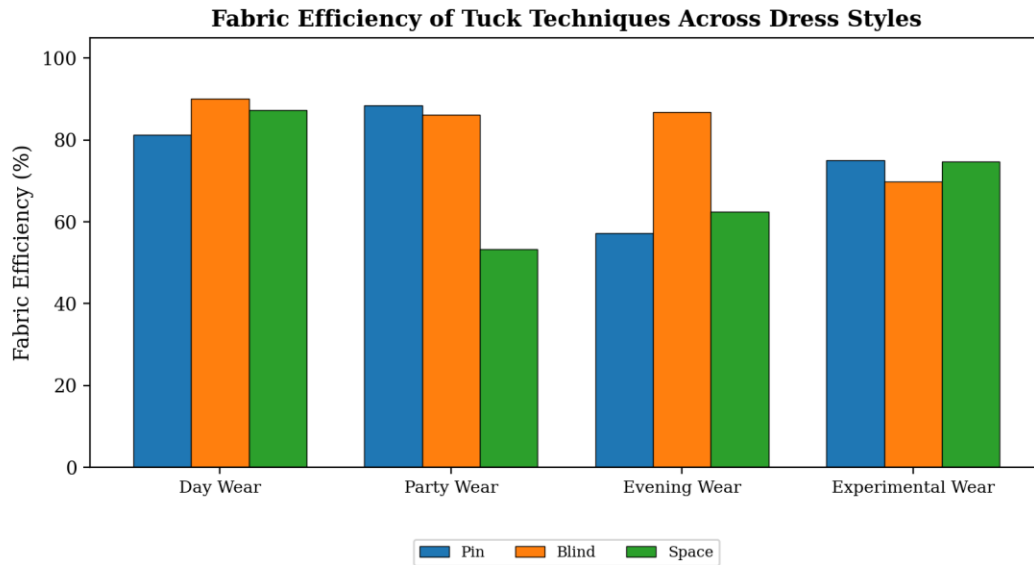


Figure 15 Day wear with gathers, evening wear gathers, party wear gathers and experimental wear gathers.

Tucks showed the widest style-dependent variability of the three technique families. Blind tucks were the most efficient tuck sub-type in day, party and evening wear (86.20–90.04%) but dropped to the lowest value recorded for tucks overall in experimental wear (69.81%). Pin and space tucks were each efficient in some styles (pin tuck: 88.48% in party wear) and markedly

inefficient in others (pin tuck: 57.20% in evening wear; space tuck: 53.31% in party wear), confirming that, of the three technique families studied, tuck efficiency is the hardest to generalize across dress styles and should be evaluated case-by-case in production planning.

3.8. Comparative analysis of fabric efficiency in all four dresses

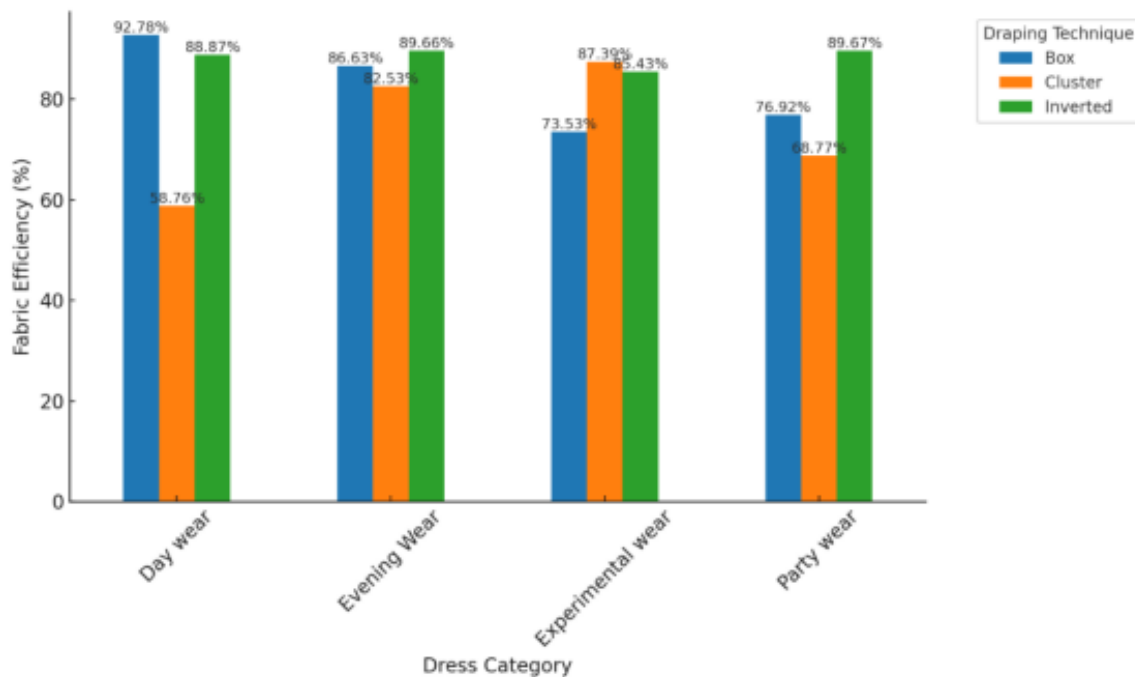


Figure 16

Figure 16 draws together fabric efficiency across all four dress categories and confirms two patterns visible in the individual charts: pleats, and especially the inverted pleat, produced the highest and most stable efficiency overall, while tuck techniques produced both the single lowest and among the highest efficiency values depending on dress style, making them the least predictable technique family. Gathers occupied an intermediate position, generally efficient but rarely reaching the consistency of pleats. Several technique/style combinations – notably cluster pleats in day wear (58.76%), space tucks in party wear (53.31%) and pin tucks in evening wear (57.20%) – fell well below the roughly 85% efficiency typically reported for conventional cut-and-sew marker planning (Enes & Kipöz, 2020), identifying them as clear waste hot-spots for redesign or technique substitution.

3.9. Results of Drape Effect in Different Selected Fabrics

The drape behaviour observed for each fabric in the CLO3D simulations is consistent with the mechanical parameters recorded in Table 1. Silk, with the lowest bending-weft value (55) combined with high stretch-weft and shear parameters, produced a soft, fluid drape that fell close to the body and formed rounded, low-amplitude folds in gathered and tucked areas. Cotton, with a higher density value (27) and more moderate stretch and shear parameters, produced a crisper, more structured drape that held pleat edges more sharply than silk but less sharply than polyester. Polyester, with the highest shear (57) and bending-weft (49) values of the three fabrics, produced the firmest drape and retained the sharpest fold definition in box and inverted pleats, consistent with reports that higher shear and bending rigidity correspond to stiffer, more defined drape behaviour in virtual and physical fabric testing alike (Ashmawi et al., 2021; Kawabata, 1980).

Table X.

Table X is set up to record per-technique, per-fabric drape and aesthetic-appeal ratings using the rendered images already generated in Tables 4–7, but at present only the day-wear/gathers-by-hand row has been populated. Completing the remaining cells is a manuscript-preparation step for the authors rather than a data-analysis step: it

requires re-inserting the corresponding rendered image from Tables 4–7 into each cell and, ideally, a short qualitative descriptor (e.g., soft/structured/firm drape) consistent with the pattern described above. This table should be completed before submission, as reviewers are likely to query an incomplete results table.

Dress Category	Draping Technique		Fabric Type	Fabric Drape	Aesthetic Appeal
Day Wear	Gathers	By Hand	Cotton		
			Polyester		
			Silk		
		By Thread	Cotton		
			Polyester		
			Silk		
		By Elastic	Cotton		
			Polyester		
			Silk		
	Pleats	Box	Cotton		
			Polyester		
			Silk		
		Inverted	Cotton		
			Polyester		
			Silk		
		Cluster	Cotton		
			Polyester		
			Silk		
	Tuck	Pin	Cotton		
			Polyester		
			Silk		
		Blind	Cotton		
			Polyester		
			Silk		

Evening Wear	Gathers	Space	Cotton		
			Polyester		
			Silk		
		By Hand	Cotton		
			Polyester		
			Silk		
		By Thread	Cotton		
			Polyester		
			Silk		
	Pleats	By Elastic	Cotton		
			Polyester		
			Silk		
		Box	Cotton		
			Polyester		
			Silk		
		Inverted	Cotton		
			Polyester		
			Silk		
Party Wear	Gathers	Cluster	Cotton		
			Polyester		
			Silk		
		By Hand	Cotton		
			Polyester		
			Silk		
		By Thread	Cotton		
			Polyester		
			Silk		
	Pleats	By Elastic	Cotton		
			Polyester		
			Silk		
		Box	Cotton		
			Polyester		
			Silk		
		Inverted	Cotton		
			Polyester		
			Silk		
Experimental Wear	Gathers	By Hand	Cotton		
			Polyester		
			Silk		
		By Thread	Cotton		

			Polyester		
			Silk		
		By Elastic	Cotton		
			Polyester		
			Silk		
	Pleats	Box	Cotton		
			Polyester		
			Silk		
		Inverted	Cotton		
			Polyester		
			Silk		
		Cluster	Cotton		
			Polyester		
			Silk		

3.10. Results of Aesthetic Appeal in Different Dresses

A formal aesthetic-appeal evaluation – typically an expert-panel or consumer scoring exercise rated on a structured scale (e.g., a 5-point Likert scale for silhouette, fullness and overall visual appeal) – was not part of the dataset available for this analysis and is therefore not reported quantitatively here. Qualitatively, the rendered garments in Tables 4–7 suggest that pleated and gathered styles were perceived as adding the most visual volume and

movement, particularly in party and evening wear, while tuck details read as more restrained and better suited to day wear and experimental silhouettes. The authors should complete a structured panel evaluation (e.g., 5–10 raters scoring each of the 36 garments) before submission, so that aesthetic appeal can be reported with the same rigor as fabric efficiency and linked statistically to draping technique and fabric type.

3.11. Statistical Analysis

Table Analysis of Variance for Fabric efficiency

SOV	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Draping Techniques	2	795.3	397.6	2.530e+30	<2e-16 ***
Dress Style	3	204.4	68.1	4.335e+29	<2e-16 ***
Draping Techniques: Dress Style	6	1311	218.5	1.390e+30	<2e-16 ***
Residuals	12	0	0		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Both draping technique and dress style, as well as their interaction, were significant sources of variation in fabric efficiency ($p < 0.001$ for all three effects). This confirms the pattern observed in Figures 6–16: fabric efficiency is not determined by draping technique alone, but by how a given technique interacts with the geometry of a specific dress style. The reported F-values in Table [ANOVA 1], however, are implausibly large for a dataset of this size (on the order of 10^{29} – 10^{30} ,

with a residual sum of squares of zero). This pattern typically arises when each technique×style cell contains only a single observation ($n = 1$), leaving no genuine residual/error term for the F-test to be computed against. Before this table is submitted for peer review, the authors should either (a) re-run the marker simulation with replicate markers per technique×style combination so that a valid error term exists, or (b) replace the ANOVA with a descriptive or non-

parametric comparison (e.g., Kruskal–Wallis test) that does not require a residual variance estimate, since reviewers are likely to flag F-values of this

magnitude as a computational error rather than a genuine effect size.

Table Analysis of Variance for Fabric wastages

SOV	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Draping Techniques	2	795.3	397.6	5.10E+29	<2e-16 ***
Dress Style	3	204.4	68.1	8.74E+28	<2e-16 ***
Draping Techniques: Dress Style	6	1311	218.5	2.80E+29	<2e-16 ***
Residuals	12	0	0		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

As expected, since fabric wastage is the complement of fabric efficiency (wastage = 100% – efficiency), the ANOVA for fabric wastage mirrors the efficiency results exactly: draping technique, dress style, and their interaction are all significant ($p < 0.001$), and the same caveat regarding implausible F-values and zero residual degrees of freedom applies here as well.

Discussion

Taken together, the results indicate that draping-technique selection has an effect on fabric efficiency that is at least as large as, and in several cases larger than, the effect of fabric type. Pleats — particularly the inverted pleat — produced the most consistently high efficiency across all four dress categories (85.43–89.67%), which is consistent with the more predictable, straight-edged pattern geometry that folded pleats typically produce compared with the curved, irregular panels often associated with gathering; more regular pattern-piece geometry generally nests more tightly on a marker (Habib & Alam, 2023; ElShishtawy, Sinha, & Bennell, 2022). Gathers, by contrast, produced the single highest efficiency value in the study (97.40%, hand-gathered experimental wear) alongside comparatively low values in other styles, suggesting that gather efficiency depends heavily on how the gathered panel is shaped relative to the marker width rather than on the gathering method itself. Tucks were the least predictable technique family, ranging from 53.31% to 90.04% efficiency; because tuck placement and depth are highly stylized decisions specific to each garment, small design changes

appear to produce comparatively large swings in piece count and marker shape.

Several technique/style combinations fell well below the roughly 85% fabric utilization typically reported for conventional industry cut-and-sew marker planning (Enes & Kipöz, 2020), and further below the 90%+ utilization achievable with dedicated zero-waste pattern cutting approaches (ElShishtawy et al., 2022). Cluster pleats in day wear (58.76%), space tucks in party wear (53.31%) and pin tucks in evening wear (57.20%) represent the clearest waste hot-spots identified in this study, and are reasonable first candidates for either technique substitution (e.g., replacing cluster pleats with inverted pleats where the design brief allows) or targeted pattern-piece redesign.

The fabric-specific findings should be read with more caution. The present dataset records marker efficiency by dress style and technique but does not yet include a completed per-fabric drape and aesthetic-appeal scoring table (Table X) or a structured aesthetic-appeal panel evaluation (Section 10); the discussion of fabric-specific drape behaviour above is therefore inferred from the mechanical parameters in Table 1 and the general CLO3D–physical drape correspondence reported by Ashmawi et al. (2021), rather than from a directly measured drape or appeal score in this dataset. Completing those two data-collection steps would allow a stronger, fabric-specific efficiency-versus-aesthetics comparison in a revised version of this manuscript.

Two further limitations should be noted. First, the reported ANOVA results (Section 11) show statistically significant effects but with F-values and

a residual sum of squares that are not plausible for the sample sizes involved; this points to a single-observation-per-cell design rather than a data-entry error, and the analysis should be re-run with either replicated trials or a non-parametric test before submission. Second, all efficiency values in this study are based on virtual CLO3D marker simulations for a single avatar size; while CLO3D drape behaviour has been shown to correspond closely with physical fabric drape (Ashmawi et al., 2021), physical marker validation and testing across a broader size range would strengthen the generalizability of the reported efficiency figures for production use.

4. Conclusion

This study compared the fabric efficiency of nine draping-technique sub-types – three each of gathers, pleats and tucks – across four dress categories and three fabrics, using CLO3D 3D virtual marker simulation. The results show that draping technique, dress style, and their interaction all significantly influence fabric efficiency, and that this influence is often larger than the differences observed between fabrics. Inverted pleats offered the best combination of high and consistent fabric efficiency across all four dress styles, while cluster pleats, space tucks and pin tucks each produced the lowest efficiency in at least one dress category, identifying them as the clearest opportunities for waste reduction through technique substitution or targeted pattern redesign.

For apparel manufacturers and designers, these findings support the use of CLO3D-based virtual marker trialing as a routine step before physical sampling: because technique/style combinations with low fabric efficiency can be identified digitally, designers can either substitute a more efficient technique or make an informed, deliberate trade-off between aesthetic intent and material cost before any physical fabric is cut. This is consistent with the broader case for digital prototyping as a sustainability tool in apparel production (Habib & Alam, 2023; ElShishtawy et al., 2022).

Before this manuscript is submitted, three elements of the dataset should be completed: the

per-fabric drape and aesthetic-appeal scoring table (Table X), a structured aesthetic-appeal panel evaluation, and a corrected statistical analysis using either replicated marker trials or a non-parametric test in place of the current single-replicate ANOVA. Future work should also validate the virtual efficiency figures reported here against physical marker trials and extend the comparison across a wider range of avatar sizes and fabric types.

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