https://doi.org/10.53230/tgm.1310-912x.2026.0005.03

ОРТОГОНАЛЕН АНАЛИЗ НА ГЕОМЕТРИЯТА НА НАДИПЛЯНЕ НА КРЪГЛИ ПОЛИ

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ORTHOGONAL ANALYSIS OF THE DRAPING GEOMETRY OF CIRCULAR SKIRTS

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Abstract:

The aesthetic and functional performance of a garment is largely determined by its draping geometry, which results from the complex interaction between fabric mechanical properties and the cut and construction of a given style. Drape is conventionally evaluated through the projected silhouette generated when a textile sample or garment falls freely under its own weight, most commonly via the Cusick drape test and its derivative image-analysis methods. The paper investigates an orthogonal draping geometry of selected garment styles, of varying number of seams, in which two-dimensional orthogonal projections of the draped form are extracted, digitized, and quantitatively compared across style variants. The methodology combines image-processing techniques to determine key drape parameters—draped area, perimeter, node number, and node geometry—for each analyzed style. The orthogonal projection approach allows the spatial fold distribution and asymmetry of the draped form to be assessed independently along defined cross-sectional planes, providing a more detailed geometric description than the conventional single-plane drape coefficient. The results clarify how style-specific construction parameters (e.g., flare, seam placement, length) influence the resulting draping geometry and support more accurate prediction and design of garment drape behavior.

Keywords: *drape geometry, skirt style, seams, image analysis.*

INTRODUCTION

The draping behaviour of a textile material is one of the most important visual and functional characteristics of a final garment, since it directly affects how a fabric conforms to the body and forms folds under its own weight [1]. Drape is not a simple, single-valued fabric property; rather, it emerges from a combination of low-stress mechanical parameters— bending rigidity, shear stiffness, weight, and thickness— together with the geometry of the pattern pieces and the way of assembling it into a finished style [2]. For this reason, drape behaviour measured on a flat fabric sample does not always correspond directly to the drape exhibited by the same fabric once it has been cut and sewn into a specific garment style, which has motivated continued research into methods that connect fabric-level drape testing with style-level (garment-level) drape assessment [1].

The most widely used reference method for drape evaluation remains the Cusick drape test, in which a circular fabric specimen is suspended over a smaller circular support and the projected shadow of the draped sample is analysed to calculate the drape coefficient and the number of nodes (folds). Over time, this principle has been adapted from simple photographic shadow analysis to digital image-processing techniques, enabling more precise and repeatable extraction of the draped contour, draped area, and circularity of the projected shape [3]. In parallel with physical testing, the rapid development of 3D garment simulation software (CLO3D, OptiTex, Style3D, Browzwear) has enabled drape analysis to be performed directly on virtual garment prototypes rather than on flat fabric swatches alone [4,5]. In this context, orthogonal projection has become a key analytical tool: the draped 3D garment surface is projected onto a transverse plane to generate cross-sectional contours along the garment length, from which draped area, drape ratio, and fold displacement can be calculated at multiple positions. This orthogonal projection methodology has been successfully applied to compare digital and real prototypes of flared skirt styles, showing good correlation between simulated and physically measured drape parameters and confirming its suitability for evaluating style-dependent drape behaviour in a reproducible, position-resolved manner [6]. Several recent works have specifically addressed how the style geometry— flare angle, hem circumference, panel number, and garment length — governs draping outcomes. Comparative analyses of flared skirt styles of varying angle and length have demonstrated systematic relationships between circular-cut geometry and the resulting drape coefficient and hemline silhouette. Similarly, investigations of knitted flared skirts evaluated on 3D-printed body postures have shown that drape parameters obtained from fully formed garments differ measurably from those of flat-fabric drape tests, reinforcing the need for style-specific, geometry-based analysis rather than reliance on fabric-only drape data [3]. Comparable findings have been reported for traditional garment styles, where the virtual and real drapability of silk fabrics used in Hanbok construction were compared to isolate the influence of style-specific cut and fabric anisotropy on drape outcome [7]. Despite this progress, most existing drape-assessment methods still characterize drape using a single overall coefficient or a limited number of projection planes, which provides only an aggregated description of a three-dimensional, often asymmetric draped form. An orthogonal multi-plane analysis — in which projections are taken along several perpendicular axes or positions of a garment style— offers the potential to capture local variation in fold distribution and asymmetry that a single-plane drape coefficient cannot resolve [8]. Building on this gap, recent simulation-based frameworks have proposed kinetic and physics-based draping models capable of reproducing anisotropic, position-dependent drape behaviour with improved accuracy relative to classical single-coefficient approaches. Recent research further highlights the importance of integrating geometric

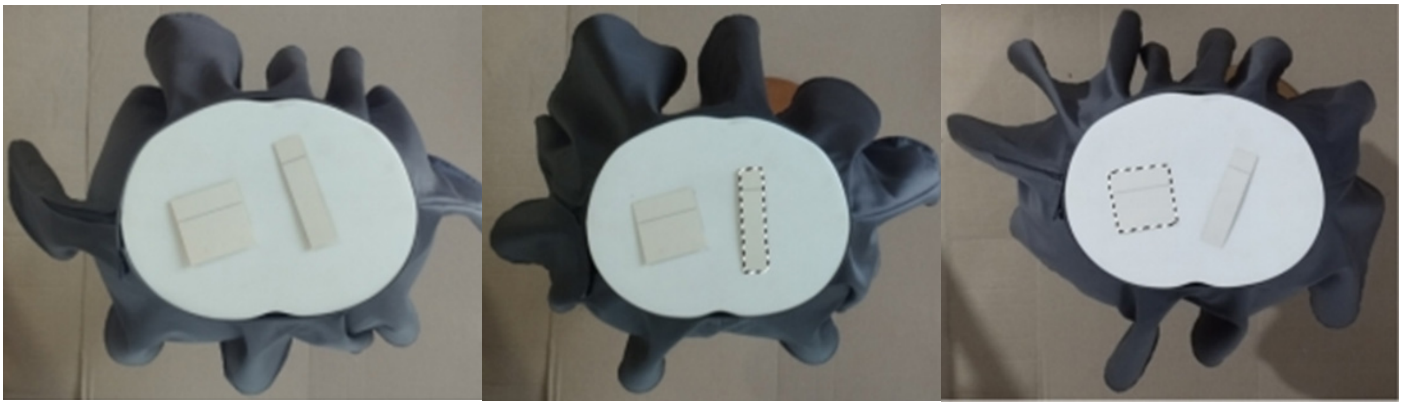
descriptors with simulation-based approaches to improve the realism of virtual garment systems [9-12]. The aim of this paper is to apply an orthogonal analysis approach to the draping geometry of selected garment styles with various numbers of seams, combining image-based and/or 3D-simulation-based orthogonal projection techniques to quantify draped area, drape perimeter, and node distribution at multiple cross-sectional positions. By comparing these parameters across style variants, this study seeks to clarify how style-specific construction parameters and seam numbers influence node geometry and to contribute a more spatially resolved methodology for drape characterization, applicable to both physical fabric testing and virtual 3D garment prototyping workflows.

EXPERIMENTAL PART

Two circular skirts were manufactured: style 1 (full-circle cut) and style 2 (1/2 circle cut). The patterns were cut for size 36, slim stature, and medium posture. The basic construction is performed with two side seams, class 1, stitch type 301. Each style was produced with three seam configurations: 2, 4, and 6 seams. The 4-seam construction, compared to the basic construction, contains two additional seams that divide the pattern cuts in half. Thus, the two additional seams are located in the middle of the front and the back side of the styles i.e. the centre front and centre back seam. In the 6-seam configuration, each pattern cut is symmetrically divided into 3 parts. All the styles investigated are manufactured from the same shell fabric, of Cotton 97% and elastine 3% fibre composition and fabric weight of 190g/m2. Garments were placed on a mannequin doll cut in a waist cross section and photographed from top position. Images were calibrated using a reference rectangle and analysed using digital image processing to extract drape parameters, including the draped area (P), perimeter (L), node number (Nn), node peak and trough length, depth and distance, and angular spacing (α) of the nodes. Three repeated measurements were performed for each sample and average values were used for analysis.

RESULTS AND DISCUSSION

Photographs from the top view of the styles mounted on a mannikin are shown in Figures 1 and 2.



2 seams *4 seams* *6 seams*

Figure 1: *Orthogonal photographs of style 1*



2 seams *4 seams* *6 seams*

Figure2: *Orthogonal photographs of style 2*

The observation of Figure 2 shows that the styles having 2 seams have nodes of smaller width. With increasing the seam number to 4, the styles obtain larger nodes. After increasing the seam number to 6 seams, the styles obtain the greater number of nodes but of smaller width. This can be especially observed for style 1 full circle skirt of 6 seams where the nodes became more frequent and of smaller width.

The drape parameters of the top-view image/drape analysis, are summarized in Table 1.

Table 1: Orthogonal drape parameters obtained from top-view analysis.

Sample		Draped area [cm^2]	Draped perimeter [cm]	Number of nodes (N_n)
Style 1, circular skirt	2 seams	300	155	10
	4 seams	384	152	10
	6 seams	356	180	12
Style 2, ½ circular skirt	2 seams	253	116	7
	4 seams	311	129	7
	6 seams	276	120	9

The results show that draped area increase when the seam number rise from two to four seams but decreased slightly after six seams are introduced. Node number remains the same when increasing the seams from 2 to 4. After increasing seam number from 4 to 6, there is increasing of the number of nodes from 10 to 12 for the full-circle skirt and from 7 to 9 for the half-circle cut skirt. Increasing the number of seams from 2 to 4 leads to an increase in fabric stiffness which affects increase of the drape projection area. However, when the number of seams is further increased to 6, a decrease in the drape area is observed for both styles. Although increasing the seam number initially improves fabric distribution and fold formation and the six-seam configuration is expected to show cumulative stiffening effect due to additional seam lines, further subdivision of the pattern introduces structural constraints that limit the natural deformation of the fabric. Consequently, the garment exhibits a more restrained drape geometry and a smaller projected drape area. Regarding the drape perimeter, it does not follow the same trend as the draped areas and is influenced by the type of style so, for style 1 it is highest for garments with 6 seams, and for style 2 it is highest for garments with 4 seams. The behavior and relationship of drape area and node number of both styles are presented graphically in Figure 3.

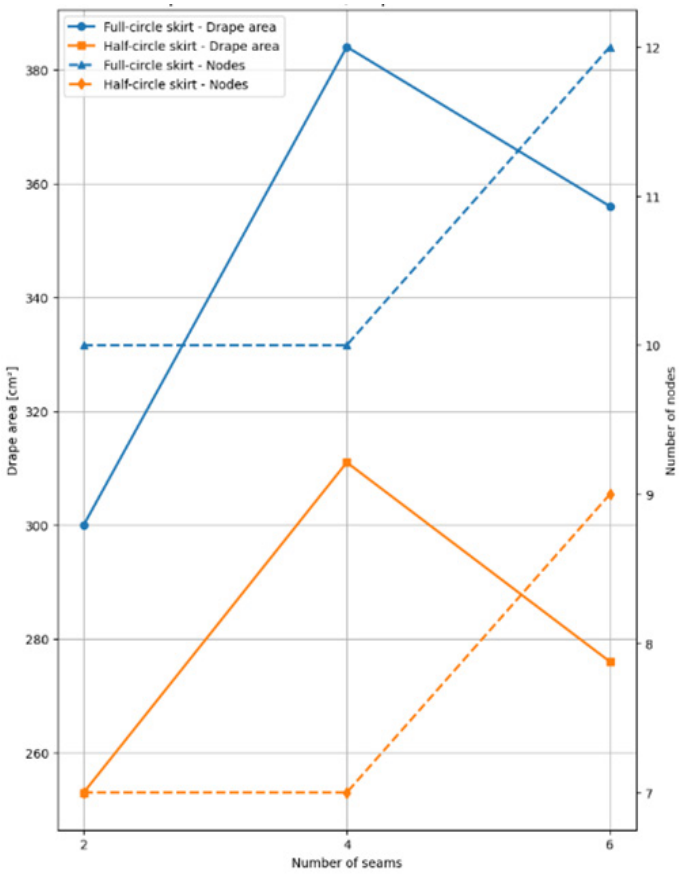


Figure 3: *Relationship between seam number, draped area and number of nodes*

Since the textile surface is an anisotropic structure with different values of mechanical properties in different directions, each draped node can show a different shape. When considering the distribution of the number of nodes (N_n) along the sides of the styles, the largest number is on the front side, followed by the back, and then the right and left with almost identical Nn. Table 2 contains the result of all node parameters (Figure 4) obtained from the top-view photograph.

It can be separated into several findings:

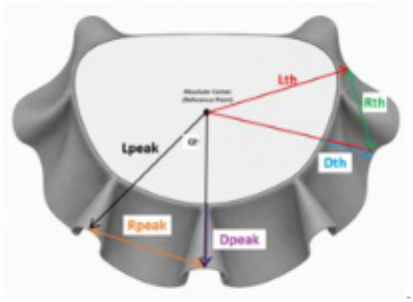
i. Node quantity is determined by N_n and the angle between two successive peaks;

ii. Node size is determined by L_{peak} and L_{th};

iii. Node depth is determined by D_{peak} and D_{th}; and

iv. Node regularity is determined by R_{peak} and R_{th}.

The description of abovementioned parameters is shown in Figure 4.



Variable	Geometric zone	Visual key	Definition
α- Alpha	Global		Angle between two subsequent node peaks [°]
L_{peak}	Outer peak	→	Peak length, the largest lengths of each node [cm]
L_{th}	Inner trough	→	Through length, the smallest lengths between each node [cm]
D_{peak}	Outer peak	→	Peak depth, distance peak - waist line [cm]
D_{th}	Inner trough	→	Through depth, distance peak - waist line [cm]
R_{peak}	Outer peak	→	Distance between two consecutive peaks [cm]
R_{th}	Inner trough	→	Distance between two consecutive recesses [cm]

Figure 4: *Legend for node parameters analysis*

Table 2: Results for node parameters in draped styles

Sample	L_{peak}	L_{th}	R_{peak}	R_{th}	D_{peak}	D_{th}	α
Style 1, 2 seams	14.6	10.9	9.3	7.2	5.4	1.8	35
Style 1, 4 seams	15.7	11.6	9.9	9.1	6.4	2.5	36
Style 1, 6 seams	13.8	9.8	7.8	5.6	5.9	2.1	30
Style 2, 2 seams	14.6	10.8	13.3	9.9	5.9	2.2	54
Style 2, 4 seams	13.4	9.7	10.6	9.6	5.6	1.8	51
Style 2, 6 seams	14.8	11.8	10.5	8.5	5.5	2.5	42

Descriptive statistical analysis was performed for all these parameters to evaluate central tendency, dispersion, and distributional characteristics. In order to save space, only the descriptive statistic results for the angles between two consecutive node peaks are presented in Table 3, but the conclusion is obtained based on the all parameters results. Still, full descriptive statistics are available as supplementary material of this research.

Table 3: Descriptive statistical analysis for angle parameter between two consecutive peaks

Criterion	Style 1, 2 seams	Style 1, 4 seams	Style 1, 6 seams	Style 2, 2 seams	Style 2, 4 seams	Style 2, 6 seams
Mean	35	36	30	54	51	42
Standard error	2.4	2.1	2.1	4.6	3.0	3.4
Median	37	34	28	55	52	38
Mode	40	41	32	61	41	27
SD	13.1	11.3	12.4	20.5	13.6	17.4
Sample Variance	171.4	127.9	152.5	420.6	186.0	304.3
Kurtosis	1.77	0.65	-0.17	0.90	-1.11	-0.28
Skewness	0.25	1.00	0.49	0.72	-0.19	0.61
Confidence level (95%)	4.8	4.2	4.2	9.6	6.2	7.1

Sample sizes were unequal across modules (n=31, n=30, n=31, n=20, n=21, n=26 per parameter, depending of node numbers), so the report emphasizes both magnitude and stability rather than relying on mean values alone. Interpretation of the results prioritized:

i. regularity of wave geometry,

ii. low variability and narrow confidence intervals, and

iii. sufficient amplitude and spacing to produce a clear but controlled drape profile.

Across the full set of parameters, full-circle skirt, four seams, was the strongest overall design. It combined the highest Lpeak mean (15.72), the lowest Lpeak coefficient of variation (12.65%), favorable Rpeak and Rth values, and relatively tight confidence intervals. In practical terms, style 1, seams 4 produced well-defined and repeatable waves without the instability seen in the extreme configurations. Half-circle skirt, four seams was the most stable half-circle configuration and the best option when low variability is the main priority. It had the lowest CV for α CV and low CV values for Lpeak and Dpeak, indicating a controlled geometry. However, its wave amplitude was less pronounced than style 1, four seams. The least favorable condition for overall consistency was the 2-seam half-circle configuration. Although it showed the highest α and Rpeak means, those gains were accompanied by large standard deviations and the widest 95% confidence intervals, indicating an unstable and outlier-sensitive configuration rather than a reliably superior one. Within Style 1, four seams maximize Lpeak while maintaining moderate α. Within Style 2, four seams reduce α relative to the 2-seam condition and preserve stable geometry.

The comparison across seam counts suggests a structural balance: two seams leave too much fabric freedom and tend to produce irregular spacing, while six seams over-constrain the skirt and reduce regularity or make the geometry more variable. Four seams provided enough control to stabilize the drape while still allowing natural wave formation. This pattern was visible in both style families, but it was strongest in the full-circle skirt. Based on the combined criteria, style 1, 4 seams demonstrated the best overall balance of uniformity, amplitude, and stability, while style 2, 4 seams was the most stable configuration within the half-circle group. Style 2, 2 and 6 seams showed reduced uniformity.

CONCLUSION

This study demonstrated that orthogonal image analysis provides an effective approach for the quantitative evaluation of garment draping geometry. Unlike conventional drape assessment based primarily on the drape coefficient, the proposed methodology enables detailed characterization of fold morphology through parameters describing node quantity, size, depth, spacing, and angular distribution. The results showed that seam configuration significantly influences the draping behavior of circular skirts. For both skirt styles, increasing the number of seams from two to four improved the distribution and regularity of the draped folds, whereas six seams increased structural constraint and reduced the uniformity of the drape geometry. Among all investigated configurations, the full-circle skirt of four seams achieved the best balance between fold amplitude, regularity, and geometric stability, while the four-seam half-circle skirt exhibited the most consistent behavior within its style category. The proposed orthogonal analysis provides a more comprehensive geometric description of garment drape than conventional area-based evaluation and represents a useful tool for objective comparison of garment styles. The methodology can support garment design optimization and may serve as a reliable framework for validating virtual garment simulations against experimental measurements in future studies.

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