Fit Validation and Assessment through Block Comparison

Emma L. SCOTT *
Fashion Should Empower Research Group, Victoria, BC, Canada

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Abstract

On-demand manufacturing is integral to sustainable practices, but product returns must be avoided to reduce waste and maximize revenue streams. With garment fit being a driving cause of returns, concerted technological engagement has been directed at acquisition of data defining apparel fit. (e.g., radial ease, compression ease, fit preference, body-shape, fit mapping, etc.) Such data has somewhat improved size selection algorithms but shed little insight on quantifying fit at the garment pattern level. For example, while a flattened 3D body mesh effectively reveals the body as 2D geometry, it offers little toward the developable garment pattern as it lacks relevance to established principles of dart manipulation and pattern-making theory. This paper discusses how a 'block comparison' approach to fit assessment better translates body data to linear dimensions suitable for both changing fit at the pattern level and improving fit prediction algorithms. Discussion will elaborate how body-blocks define 3D human morphology at the garment pattern level to establish practice for quantified fit theory while supporting traditional apparel pattern practice. The change management required for fit validation (the digital asset as tech pack) lays the foundation for automated mass customization, not as the once considered singular solution, but as a scope of solutions ranging from ready-to-wear (RTW) to bespoke. Not as the once considered singular solution, but as a scope of solutions ranging from ready-to-wear (RTW), to bespoke. With sustainable garment production being a key factor in mitigating climate change, fit validation to reduce garment returns (increasing the profitability of on-demand manufacturing) is a logical next step. In this environment, both customer and brand fit preference may align or differ without imposing on the other. From here we must consider that perhaps Industry 4.0 is better embraced with a full suite of fit intent offerings, where the change management required for RTW fit validation (digital tech packs) sets the foundation for automated mass customization, not as the once considered singular solution, but as a scope of solutions ranging from ready-to-wear (RTW), to bespoke. In this environment, both customer and brand fit preference may align or differ without imposing on the other.

Contributors

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Keywords: fit validation, body-block, block comparison, fit mapping, quantified fit, garment fit

1. Introduction

The paper "IEEE 3D Body Processing Industry Connections Assets and Transformations Definitions" [1], identifies items worn on humans as covers and the models representing humans and covers as humanoids and coveroids. *Figure 1* summarizes the three-dimensional body processing (3DBP) transformations that transpire during the creation, testing, and donning of covers in both physical and digital space. Here we utilize these assets to reinforce the critical importance of the 2D garment pattern (coveroid) and its relevance toward fit validation.

When discussing digital product creation (DPC) [2] it is natural to focus on the 3D digital asset (coveroid). This digital asset stage, where the coveroid more directly models the desired physical cover, is the 'fun' stage where texture, colour, closures, trims and other accessories bring the cover to life. It is easy to discount the preceding critical stages. Consideration for the assets representing the modeling and donning of body-worn products, however, brings awareness back to the critical importance of the 2D pattern. In virtual space, we understand the 3D coveroid to be the assembled version of the 2D unassembled pattern. Physical space practice requires the additional step of using the pattern as a template from which to cut material, but in virtual space, the pattern is wrapped on a humanoid to become the garment. Virtual space practice makes clear the coveroid exists in two states, unassembled and assembled. Within the 3DBP ecosystem we understand the pattern and garment to be inherently linked. Therefore, a mathematical understanding of coveroid geometry holds the potential for a qualitative understanding of 'fit'.

* connect@fashionshouldempower.com

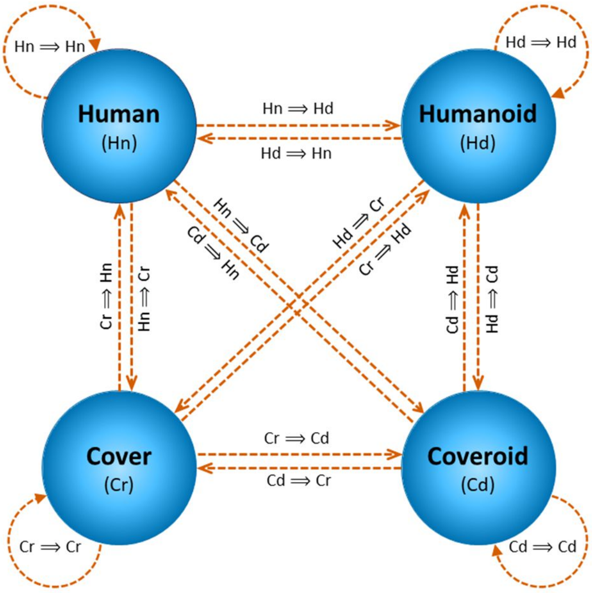


Figure 1 - The four assets summarizing the modeling and donning of body-worn products.

2. Building a Case for Fit Validation

2.1. Body Dimensions (humanoid to coveroid)

Humanoid dimensions drive coveroid development and direct cover selection. For molded product development it is possible for the 3D humanoid to directly drive product creation. Consider products developed from 2D materials, such as woven or knit fabrics. For body-worn product development this requires a construction process whereby material is cut into shapes and then joined together to create a 3D shape. Whether the material is manually cut, or machine cut, patterns guide the cutting process. While it seems logical that flattening the humanoid mesh to 2D could produce geometry suitable for material cutting purposes, this is seldom the case. While select use cases utilizing flattened humanoid geometry (UV unwrapping) have proven successful [3] the methodology has lacked widespread adoption due to conflicts with establish pattern-engineering practice. This is because the flattening of non-developable surfaces requires the addition of split lines, understood to be darts in pattern-engineering practice. Darts and other shaping devices are added to pattern geometry to reduce buckling and wrinkling and control the direction of fabric grain. [4] Research toward optimized humanoid flattening to directly achieve desirable pattern geometry is ongoing, but existing methods do not automatically nor consistently produce geometry considered developable and suitable for established pattern practice.

What the flattening of humanoids has made clear is that both 1D humanoid dimensions and 2D shaping device dimensions are essential to create 2D coveroid geometry representing human body-shape. With this understanding, comes the ability to represent 3D human form (body-shape) as 2D coveroid geometry.

2D Body-Shape = 1D Humanoid dimensions + 1D Shaping Device Dimensions

2.2. Garment Ease

Coveroid dimension beyond humanoid dimension is traditionally referred to as ease.[5] The various reasons for adding ease to pattern dimension have been well documented. [6][7][8][9] Where these key works have faced difficulty is with the quantification of shaping devices to direct ease distribution. [10] Even when considering a reverse engineering approach to design [11] discussion focusses on ease as an offset rather than geometric pattern dimension. Garment offset from a body, changes with even slight shifts in posture or movement. Hence offset is only relevant to a single moment in time. Geometric dimension, on the other hand, remains relevant through dynamic change of either material or body.

Ease may be added internally by utilizing the volume of an internal shaping device (dart) or added to a seam as additional dimension. The addition of ease to pattern perimeter boundaries is well understood. The utilization of internal shaping devices for ease distribution has remained mainly heuristic practice fine-tuned during sampling and fitting sessions. This is largely due to a lack of theory supporting body-to-garment mapping practice for customized (geometrically constrained) shaping devices. To compensate for this lack of theory, standard practice encourages the use of generic shaping devices (estimated) which are further fine-tuned during sampling and fitting sessions. [12] While study has documented improved fit resulting from customized shaping [13], use of this practice in large scale manufacture is extremely limited. Successful use-cases are made possible by an initial culling of body-shape categories. For example, directed at either women or men, then sub-categorization into age and height, resulted in reasonable estimations of group specific shaping devices, but has not led to geometrically constrained rules to direct pattern geometry.

2.3. Shaping Devices

Shaping devices remove coveroid geometry so that the 2D pattern may more closely resemble human form.[4] Unlike machining industries, apparel mapping practice generally lacks geometrically constrained relationships. [14][15] Consequently, theory to support the quantification of shaping devices is lacking. The nature of construction materials (mainly fabric) and production practice involving easing makes this possible, but such technique may also have discouraged the evolution of pattern-engineering practice better suited to geometrically constrained relationships .[16]

Easing is a sewing technique where seams of differing length may be joined by slightly stretching the shorter seam and various techniques for compressing the yarns of the longer seam. For example, it is common practice to ‘ease sleeves to a garment torso’. This means that additional circumference is added to the perimeter of a sleeve making it larger than the hole it will be attached to, and the sewing technique of easing will make it possible to join seams of differing lengths. Once attached, the eased seam creates a rounded 'cap' on the top of sleeve better suited to the curved, non-developable nature of the human shoulder. This ‘rule’ for joining sleeve to torso evolves from heuristic technique to optimize practice without the benefit of a geometrically constrained arm-to-torso relationship. Flattening of a humanoid arm, however, reveals the possibility of creating arm-to-torso geometry without ease. The resulting shape may require several shaping devices uncommon to traditional practice. If this flattened shape were to be sewn and constructed in a traditional fashion it would have several darts. Within traditional practice, when a dart is not desired, one method of hiding it is to release it for ease. It we apply this theory to our flattened sleeve; we can understand that we have quantified the heuristic rule for adding ease to a sleeve head. If after releasing the shaping devices it was determined that more ease was desired, then we would understand that ease beyond that which is required for the shape of the arm was desired.

Where heuristic technique provides the rule that ease is necessary, a constrained relationship quantifies the degree to which shaping devices have contributed to ease, as well as the amount of ease added. By understanding where shaping devices are required to maintain fabric grain and join conflicting shapes, such as sleeve to torso armscye, the otherwise heuristic distribution of ease, can be provided a constrained relationship better suited to a geometric understanding of fit. [5] Practice may continue to favour easing, but heuristic technique is quantified and provides a constrained relationship suited to algorithm and automation.

2.4. Materials

While the pattern geometry resulting from a flattened mesh is completely ineffective for use with woven materials, its effectiveness with stretch material clearly demonstrates the potential for scan-to-garment manufacturing.[3] These studies also speak to the critical role material properties play in pattern geometry and suggest there is still much to understand regarding fitting technique in stretch verse woven material. [17] What these studies clearly demonstrate, is the fact that parent blocks are relevant to a type of material. A change in materials, for example Young’s Modulus of elasticity, may create the need for a new parent block. [18]

2.5. Fit Perspective

Further complicating an understanding of shaping devices is the fact that opinions on fit will vary. For example, it may be determined that a certain body morphology requires 12cm of back waist darting. While the shaping requirement of 12 cm may be determined as fact, there will be no singular best method for achieving this shaping requirement. One practitioner may prefer for this shaping to be entirely dispersed amongst internal darting while another may want a combination of seam and internal shaping. Regardless of variation in type of shaping device the measured geometric result will be within industry standard error allowances.

2.6. Parent-Child Model

Apparel pattern practice is founded on a parent-child model whereby a parent coveroid with a satisfactory fit may be infinitely adapted to create child patterns. Once a pattern has been shaped to satisfaction, it is understood to be a parent block from which infinite child pattern iterations are possible. Used correctly, the fit of the parent is successfully passed to all child, grandchild, and family iterations. This model runs into difficulty when the original body-block is lost or distorted. This can happen with the use of archived patterns without correct knowledge of humanoid shaping devices used to direct the original parent block. In the future, digital tech packs will remain linked to both the coveroid and cover, thereby optimizing the parent-child model.

2.7. Dart Manipulation

The process of dart manipulation, also referred to as slash and spread, is critical to the reuse of the parent block.[19] Dart manipulation is the process by which a dart is relocated to another position within the pattern geometry. As this technique has roots in calculus (two vectors with a constant theta) the process is automated in all apparel CAD software. Not all pattern theory shares this mathematical foundation. In fact, it is a lack of shaping theory that is largely inhibiting digital product creation.[17]

Critical to apparel fit practice, is the art of aligning fabric grain (weft and warp of woven fabric or course and wale of knit fabric) to body geometry. This is accomplished using either internal shaping devices (darts) or through shaping applied to the pattern perimeter. Without theory supporting the quantification of shaping devices, heuristic technique is taught as hand draping practice. [20] Shaping or fitting devices strategically remove fabric to reduce wrinkling and buckling. [4] The presence of shaping devices is not always readily apparent in finished covers because the manipulation of shaping devices is critical pattern-engineering strategy. [19] When a shaping device is not desired, it may be released for ease (not sewn) or manipulated to another area in the pattern. Since many garments exist without darting (shaping devices), their significance is easily discounted if pattern-engineering techniques is not fully understood. In the case of t-shirts, the only design lines to manipulate shaping into are perimeter lines. If the t-shirt does not have side seams (seamless knits), any unwanted waist shaping darts would have to be released to ease. Consequently, body-shapes not requiring waist shaping would have zero ease, snug t-shirts, while body-shape requiring 8cm of back waist darting would end up with 8cm of waist ease.

In production environments sampling, is a known bottleneck in the concept to product pipeline While the manipulation of shaping devices is core to the evolution of garment styles, production pattern-engineering continues to be initiated from an estimation of body-shape. It is highly possible that much of what sampling is correcting for is body-shape error. It is also highly likely that a lack of theory for customized shaping devices is inhibited the evolution of pattern engineering for fully digital product creation.

2.8. Fit Error

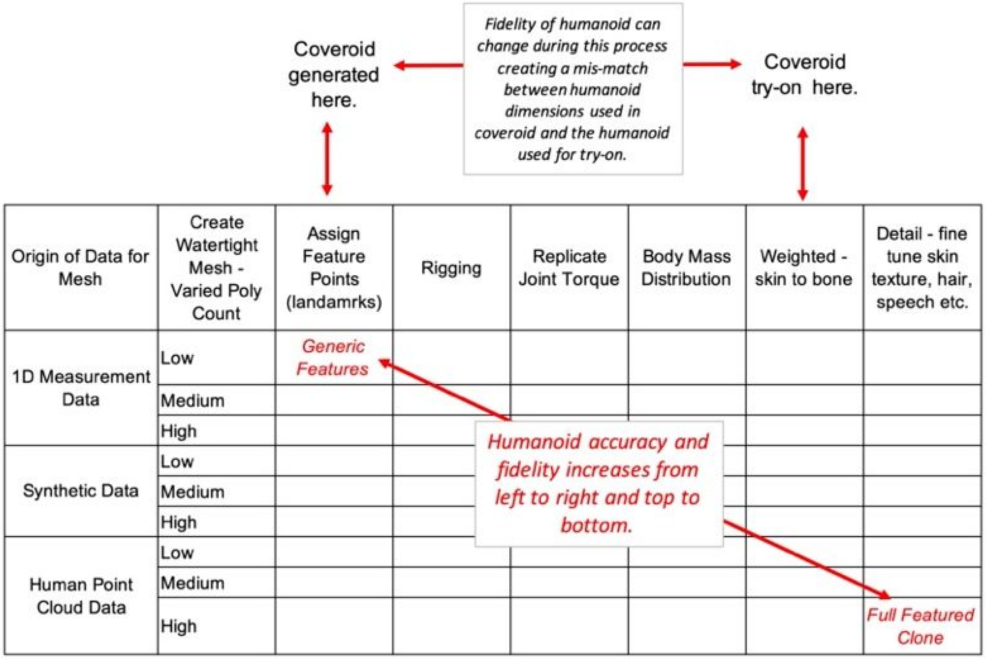
A geometrically constrained understanding of the body-garment relationship is the first critical factor effecting cover and coveroid fit. The second, and more complicated factor is error quantification. During the manufacture of covers, there are multiple opportunities for the introduction of error. Understanding and tracking this error is of critical importance to the quantification of fit. Just as the act of ‘easing seams’ has inhibited a geometrically constrained understanding of the body-garment relationship, the use of fit tolerance has masked a satisfactory understanding of fit error. Easing of seams and fit tolerance will continue to be essential tools in the manufacture of covers but the use of 3D technologies presents the opportunity to optimize that which is currently, at best, merely estimated.

Following is initial consideration for where fit error may be introduced along the ‘style concept to product’ pipeline; ***presented here in a known incomplete form to engage conversation toward a larger treatise and thorough dissemination of apparel fit and validation.***

2.8.1. Scanning Error

Figure 2 summarizes factors contributing to humanoid quality and fidelity. The vast spectrum of varied types of scan data coupled with the dynamic nature of human form contributes to perceived scan error. With machining industries achieving millimeter accuracy from scanned data, concerns toward accuracy for 3D body processing activities can be understood to be a mismatch of data or processing error. Transparency regarding quality and fidelity will be paramount for fully digital product creation.

Discerning ground truth dimensions for a human is difficult due to the dynamic nature of human form, changing dimension with motion or even the act of breathing. Are ground truth dimensions of a ribcage taken on inhale or exhale of breath? Is it better to record morning dimensions of a waist or dimensions after a day of digestion? Even with the most precise scan available, the chances of dimensional change in humans from one week to the next is high. The averaging of consecutive scans (several moments in time) has proven effective for better capturing human morphology. [21] Perhaps such practice adapted for consecutive scans over a month could better capture averaged morphology from week to week? It may well be that statistical generation of human morphology achieves an equivalent averaged ‘over time’ body-shape. Toward the goal of improved fit, further study should consider the variation in body-blocks derived from photogrammetry versus consecutive daily scans from booth scanners. Human factor study from the perspective of improved pattern-engineering may offer novel insight [22] supporting early research suggesting the usefulness of photogrammetry. [23]



Coveroid generated here.

Fidelity of humanoid can change during this process creating a mis-match between humanoid dimensions used in coveroid and the humanoid used for try-on.

Coveroid try-on here.

Origin of Data for Mesh	Create Watertight Mesh - Varied Poly Count	Assign Feature Points (landamrks)	Rigging	Replicate Joint Torque	Body Mass Distribution	Weighted - skin to bone	Detail - fine tune skin texture, hair, speech etc.
1D Measurement Data	Low	*Generic Features*					
	Medium						
	High						
Synthetic Data	Low						
	Medium						
	High						
Human Point Cloud Data	Low						
	Medium						
	High						*Full Featured Clone*

Humanoid accuracy and fidelity increases from left to right and top to bottom.

Figure 2 – Factors contributing to humanoid quality and fidelity.

2.8.2. Landmarking Error

Landmarks are critical points between which measurements are taken. Landmarking error therefore directly effects block pattern geometry. Current methods of landmarking the body can lead to flawed data analysis due to non-stable points of reference. For example, the waist landmark varies in position from the twelfth thoracic vertebrae (T12) to the fourth sacral vertebrae (S4) depending on subject height. Critical to digital product creation are methods for landmarking and measuring human form from which geometrically constrained relationships with the coveroid can be established. Since morphological landmarks are easily relocated with movement and weight fluctuation (belly button may be relocated with weight change) such points do not provide a stable base point of reference from which to study dimensional change over time (4D fittings). Traditional methods of locating the waist relative to a morphological landmark (belly button or the smallest circumference) do not hold true across the population. Further study should consider stable landmarks relative to the virtual skeleton (rig) to better connect the humanoid-to-coveroid through the DPC pipeline. Some practitioners have suggested percentage division of the spinal column between the underarm (approximately skeletal mesosternale) and crotch. [24] Such positioning could approximate spinal joints sufficient for apparel and animation practice. For example, identification of a low-waist on the spinal column at the most flexible lumbar joint, between L4 and L5 could establish a waistline dividing the upper and lower torso at a location congruent with body movement. Study of morphology as percentages has proven effective in health and wellness [25][26] and may offer a path forward for dynamic study of garment to body interaction (4D fittings). Positioning the waist landmark with reference to vertebrae joint within the spinal column would better establish geometrically constrained body-to-pattern relationships across boundaries of age and gender.

2.8.3. Measuring Error

Coveroid patterns are commonly symmetrical, so it is common for measurements coming from humanoid scan data to have been made symmetrical; critical data van be lost in the process. Left and right sides of the body should be measured independently, with symmetry and dysmorphia balancing handled within geometrically constrained rules for the body-to-pattern relationship suited to engineering theory. For example, ease may be distributed to reconcile asymmetry in left and right sides of the body.

Measuring error can also originate from inappropriate humanoid. There will be cases when it is best to develop a coveroid from moment-in-time dimensions, and cases where averaged over-time dimensions are more appropriate. In the case of form fitting garments (bridal and eveningwear) soft body humanoids capable of mimicking tissue displacement will be critical. Breast supporting garments reposition breast volume and shaping garments redistribute abdomen tissue changing human dimensions. The effects of inner layer coveroids on humanoids to drive the development of outer layer coveroids is not yet readily available but research and development toward soft body humanoids is ongoing.[27][28]

2.8.4. Body Block Error

The body-block, as a 2D representation of body-shape, is a type of origami. Any complex shape may be reduced to origami.[29] Such methods, however, are not necessarily suited to covers the origami act of folding fabric would create unwanted bulk. Further, a purely origami approach would not adhere to the principles of fit to maintain desired fabric grain. A body-block has elements of origami such as internal darts, but seamlines replace areas where folding would create undesired bulk.

Body-block seamlines segment the body into patches at key apparel landmarks: head, neck, torso, arms, hands, legs, feet. Each of these areas is further sub-divided at areas where movement changes body dimensions. The limbs are separated from the torso and sub-divided into upper and lower. The torso is separated from the neck, arms, and legs, then divided into quarters to separate left from right (at centers) and front from back (at sides). These segments act as reference points between the humanoid and coveroid. They create 3D body patches on the humanoid for measuring dynamic dimension change. They direct coveroid geometry specific to each patch.

To say there is one correct representation of 3D humanoid data as 2D coveroid geometry is incorrect. For example, a required dart may be distributed as a single dart, broken into three, or be removed from a perimeter seam in lieu of an internal dart. Seamlines may be moved forward, backward, or completely removed. Practitioners have presented valid arguments to support the aesthetic placement of side seams [30] but perspective remains subjective. A ground truth for measuring error must therefore reference 1D measurements taken from the humanoid. As dimensions change with movement, A-pose has been established as the ground truth pose.

When translating 1D measurements to 2D coveroid geometry error is expected (as with all origami representations) but the goal of course is to achieve as close to base 1D measures as possible. Since the body-block includes added dimension for shaping devices, the unassembled coveroid is not suited for direct comparison to the humanoid. Therefore, body-block error must compare dimensions between the 3D humanoid and the assembled coveroid. Further study should consider an acceptable degree of error. While placement of shaping devices may remain subjective, quality of the block may be assessed based on a compromise between a degree of error and that which is suitable for production (developable). For example, a flattened humanoid is a body-block, but it is not suited for all types of production.

2.8.5. Unassembled Coveroid Error

For effective manufacture, it is expected that all pattern geometry result in smooth curves or lines. During the process of truing and smoothing lines and curves, a degree of error is introduced and considered reasonable in exchange for smooth construction seams and desired fabric drape. Minimizing error, witnessed as undesired fabric buckling and wrinkling [4], is accomplished through the strategic placement of shaping devices to control fabric grain. The base positioning for fabric grain is warp aligned with body center and weft aligned with hip and bust.[20] Alternative grain strategies will reference this base to achieve any desired effect. ***Slight changes in morphology will necessitate changes to shaping devices (seams and internal darting).*** Current practice, even within a digital product creation (DPC) pipeline, continues to rely on 'estimated' shaping devices and sampling to correct fit errors, resulting from a mismatch of shaping devices. Therefore, ***the continued necessity for sampling is at least partially attributed to a mismatch of shaping devices to body-shape.***

2.8.6. Cover Error

Sustainability initiatives are beginning to consider circular product lifecycles. This offers the opportunity to gathering data on the shrinkage and aging of materials used in garment construction. Outside of the DPC pipeline maintaining a historic record of the freshly produced garment for comparison against the aged garment is cumbersome to say the least. In the future the digital product complete with asset and digital tech pack, could be expanded to include a longevity report. Such data, accessed via digital product markers, could be key for tracing carbon offsets.[2] This transparency may also influence consumer buying habits.

2.8.7. Fitting Error

The humanoid measurement data used to initiate the pattern process is not always directly related to the humanoid (fit model) which will be used for test fitting (sampling and try-on). Alternately, coveroids may be generated from statistical size data (e.g., size charts) with only moderate relevance to the fit model. ***Such practice intertwines shaping devices and ease into a single data set rather than the body-shape and fit-preference data sets previously suggested***. With even slight variations in bust darting, waist shaping, shoulder slope and back curvature causing variation in body-block coveroids this practice is not suited to a qualitative understanding of fit.

2.8.8. Grading Errors

Grading is a parameterization process by which a pattern is sized either larger or smaller to derive a full product size range from a base fit model size. The process is effective at creating other sizes of similar body shapes. Where difficulty arises, and where parameterization fails, is in attempts at grading for body-shape. [12] While the terms size and body-shape are often used interchangeably, from a pattern-engineering perspective there are important differences. Without a pattern-engineering understanding of constrained body-shape relationships (humanoid dimensions plus shaping devices) current methods of grading cannot possibly grade for shape.[17]

2.9. Fit tolerance

Bodies are non-static, changing with every breath. A cover precisely formed to a body will not account for natural weight fluctuations that occur from morning to night or month start to end. With body-shape itself being non-static an estimation of fit would seem sufficient. It also seems reasonable that slight deviations away from fluctuating body-shape could be adequately accommodated with ease allowances. Hence, traditional fit practice is founded on the reasoning that averaged shaping devices combined with ease will provide sufficient fit tolerance to accommodate variations in body-shape and fit-preference. A multi-billion-dollar garment industry would appear to support this but, here again, the 3DBP ecosystem reveals a different story. DPC continues to be inhibited by a need for physical samples to correct nuances eluding virtual practice. ***It is the opinion of this author that fit tolerance based on estimation (driven by a lack of theory supporting body-block shaping) is the root cause inhibiting fully DPC and widespread adoption of 3D technologies.***

The existing apparel model, however, rests as proof of the significance of fit tolerance at extending the range of wear for apparel products (covers) and hints at future possibilities for DPC when provided a mathematical foundation. An ability to quantify body-shape at the coveroid level would present new opportunities for body-shape sizing strategies. This would lead to fit tolerance strategies supported by geometrical coveroid dimension.

3. Fit Validation

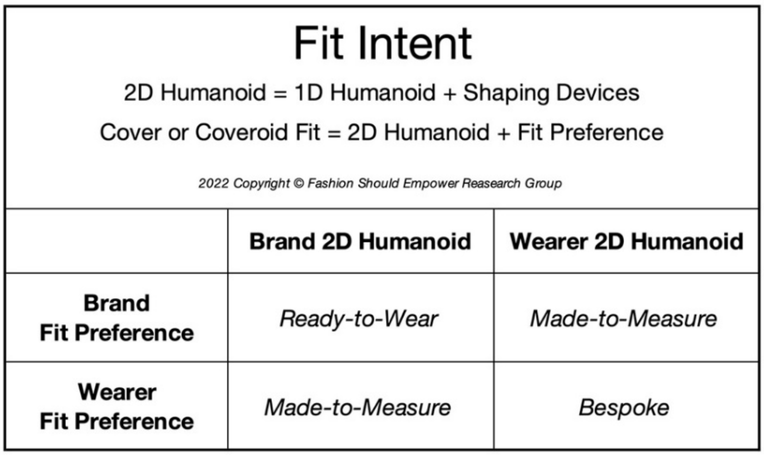
The term ‘Fit’ broadly describes the relationship between the human and cover, or humanoid and coveroid. Ease and fit are often used interchangeably but this is incorrect. The ratio of ease to body dimensions is of key concern to the aesthetics of fit, but ease alone does not adequately define a customer’s preference for fit nor the fit intent of the style. Critical to fit validation is fit perspective. If a customer desires a bra in a band size smaller than brand fit intent dictates, the brand must be able to deliver on the customer’s request. Here the customer and brand have differing fit perspectives. In this case, the customer’s fit preference is for ease (negative) resulting in a smaller size than deemed suitable by the brand.

Much research has been dedicated to methods for ease assessment and fit validation.[9][31][32] [33] Where these studies have faced difficulty, is in the geometric quantification of body-shape affecting distribution of ease. [10] Where body-shape has been considered [34] shaping is focused on a gender sub-group and not discussed in the broader sense of cross-population.

As there is no single best way to achieve any given fit scenario it is possible for different pattern geometry (a result of differing fit-preference) to achieve the same quantified fit result. For example, 4cm of ease added to the side seam versus 4cm ease gained by releasing darting. In fact, there are multiple means by which this same fit scenario could be achieved. In fact, there may be multiple different ways to achieve any given fit scenario. While it would seem this makes quantifying impossible, this is not true! While a preference for fit is established through the **subjective** use of principles of fit (grain, set, line, balance, and ease distribution), fit intent remains **objectively** measurable as geometric dimension. This concept is fundamental toward a geometric understanding of fit within an industry reliant on creative expression.

3.3. Geometric Understanding of Fit Intent

With recognition of the body-block as a geometric representation of body-shape, ***fit intent may be numerically expressed.*** Figure 3 illustrates how fit intent is applied for a mathematical definition of the difference between ready-to-wear (RTW), made-to-measure (MTM), and bespoke garment fit. Here we build on the previously established two-factor understanding of fit: body-shape plus fit preference equals garment dimensions.



Fit Intent

2D Humanoid = 1D Humanoid + Shaping Devices

Cover or Coveroid Fit = 2D Humanoid + Fit Preference

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	Brand 2D Humanoid	**Wearer 2D Humanoid**
Brand Fit Preference	*Ready-to-Wear*	*Made-to-Measure*
Wearer Fit Preference	*Made-to-Measure*	*Bespoke*

Figure 3 – A high level perspective on fit.

3.2. Digital Tech Pack

Discussion on connecting the multiplicity of steps involved with digital production creation DPC and the use of digital tech packs to summarize the humanoid-to-coveroid relationship are beginning to take hold. [2] [35] Here we initiate discussion on how fit intent may be defined at the digital tech pack level suitable for a future where automation of bespoke fit is possible, although no longer required due to improved RTW body-shape size ranges combined with more sustainable MTM options!

Central to all quantified fit discussions herein, is the body-block as a geometric representation of human morphology. From this starting point, fit quantified design becomes an additive pattern-engineering process with definable data sets. The parent block becomes the result of humanoid, shaping device, and fit preference dimensions. If a decision is made to delegate all fit decisions (block geometry) to the parent block and all style decisions (split-lines, trims, facings, pockets) to the derivative child patterns, a foundation for quantified fit at the digital tech pack level is established.

3.4. Testing Fit Validation

Here we consider fit validation using novel scan-to-pattern theory.
Intelligent Shaping™ generates digital tech pack data as fit quantified parent blocks using the data sets identified in Figure 3.

- **Body-block data sets** are driven from humanoid scan data.
- **Fit preference data sets** are generated from user inputs to establish the desired fit intent.

As discussed in a recent Interline article [35], the task of initiating a digital tech pack suitable for DPC requires automation so designers may focus on their unique skill set. Intelligent Shaping™ readies a design concept for the DPC pipeline by translating subjective design decisions regarding fit intent to objective coveroid geometry. User inputs include choices for ease and opportunities to change default darting and seam locations (shaping devices). The software is built around proprietary Clone Block™ pattern-engineering theory offering gender and age neutral body-shaping strategies. [24][36] As fit perspective is subjective, a parametric sketch updates in real-time to show users the objective results of their fit decisions. The software acts a design aid for creatives not an attempt at replacement.

3.4.1. Fit assessment set-up.

Three data sets are required for any assessment: fit model humanoid, customer humanoid, and fit-preference data. The following workflow precedes any fit assessment:

1. Measurement data was extracted from both the fit-model and customer humanoids using the proprietary measurement extraction software within Intelligent Shaping™.
2. Using the parametric sketch, fit-preference data choices were established and saved.
3. Body-blocks were generated for both humanoids.
4. Garment blocks, using the assigned fit-preference data, were generated for both humanoids.

3.4.2. Ease Assessment

An ease assessment determines how the fit intent of the garment is changed by the customers body-shape. The customers body-block is central to this fit assessment. Critical to the accuracy of this assessment is a consideration for internal shaping devices against pattern geometry dimensions.

Ease = RTW Garment Block – Customer body-block

3.4.3. Error Assessment

An error assessment determines how the fit intent of the garment varies from an equivalent bespoke garment. Critical to the accuracy of this assessment is a consideration for internal shaping devices against pattern geometry dimensions.

Error = RTW Garment Block – Customer Garment Block

3.4.4. Size Selection

Size selection can be considered from the perspectives of customer and brand. Assuming the brand's identified fit preference satisfies the customer, the RTW garment most closely matching the garment's key dimensions is chosen using the following procedure:

1. Choose a size as per brand size chart that most closely matches the customer's key girth dimensions.
2. Use the above formula (section in 3.41) to calculate the ease (fit) resulting from the interaction of coveroid geometry and customer body-shape (body-block).
3. Size is chosen to best achieve desired fit preference:
   a. If the customer agrees with brand fit preference vary size to ***match brand ease*** for largest key girth.
   b. If customer fit preference differs from brand, vary size to achieve ***customer desired ease*** for largest key girth.

Summary

We have utilized the assets and transformations within the 3DBP ecosystem to establish the unassembled 2D coveroid and the 3D assembled coveroid (digital asset) as different states of the same coveroid entity. With this understanding we suggested the optimization of digital product creation (DPC) can be achieved by initiating the digital asset as a digital tech pack in Intelligent Shaping™ software. With this digital tech pack, we then detailed how a 'block comparison' approach to fit assessment better translates body data to linear dimensions suitable for both changing fit at the pattern level and improving fit prediction algorithms.

Critical to the optimization of digital product creation for fit validation we identified the following process for parent block development:

1. Human morphology (body-shape) is rendered as 2D coveroid geometry
2. A quantified fit parent block is achieved through an additive pattern-engineering approach whereby fit preference is strategically added to a body-block (body-to-garment) via a parametric sketch.
3. Change-management strategy capitalizes on the established apparel practice of parent-child pattern families with the following caveats:
    a. Fit decisions (block geometry) are delegated to the parent block in Intelligent Shaping™ software.
    b. Style decisions (e.g., split-lines, trims, facings, pockets) are delegated to child iterations in industry standard apparel CAD applications.

Further study should validate the effectiveness of Intelligent Shaping™ software at:

1. Building blocks representative of 2D body-shape.
2. Guiding the user through the building of fit quantified parent blocks.

Conclusion

Discussion on optimizing digital product creation has often suggested the need to ‘eliminate’ sampling. To suggest sampling will be eliminated from the design process is to suggest human ingenuity will cease to be relevant. Here we have offered a means for real-time rendering of design choices, but we have not suggested choice should be controlled. Design teams will continue to make comprises based on varying fit perspectives. Consumers will not always agree with brand fit perspective. While body-shape quantification is possible (pending validation), varying fit preference perspectives will remain fundamental to the art of apparel design and dressing. Redundancies in sampling due to body-shape error can be eliminated but within the process of optimization, room for individual perspective must remain.

A driving goal of apparel digitization has been mass customization. As we come close to realizing this goal, we must reflect on whether this is the most sustainable choice. The limits of RTW fit are well known, but their ability to accommodate vast ranges of morphologies speaks to the potential for improved fit given reliable qualitative data. For example, research strongly supports RTW sizing focused on body-shape better addresses customer fit requirements.[13] The opportunities for improved fit tolerance strategies to drive body-shape sizing systems from body-blocks should be revaluated from a perspective of body-block shape categories. Fit tolerance improved RTW (reducing garment returns increasing the profitability of on-demand manufacturing) may be the logical next step toward sustainable garment production mitigating climate change. It can at first appear counter intuitive that digital product creation (DPC) would be concerned with fit perspectives other than MTM or bespoke. However, a brand’s on-demand RTW offering can be a key change management strategy for implementing the digital tech pack and advantages of quantified fit.

Following, we must contemplate if mass customization should remain a singular focus. Individual fit preference has long been understood to be complex. [37] Machine learning has much to offer toward assessing fit preference but to effect fit at the coveroid level we must now use the above formulas for ease to translate fit preference to geometric definition. [38] Further study must then consider the degree to which changes to fit preference may compromise product integrity. For example, if a consumer prefers a stretch pant with less ease than advised, should the MTM fit preference order be fulfilled? Perhaps Industry 4.0 is better embraced with a full suite of fit intent offerings where the change management required for RTW fit validation (digital tech packs) sets the foundation for automated mass customization, not as the once considered singular solution, but as a scope of solutions ranging from ready-to-wear (RTW), to bespoke. In this environment, both customer and brand fit preference may align or differ without imposing on the other.

References

[1] W. Glascoe, J. Schulz, E. Scott, and C. Mcdonald, “IEEE 3D Body Processing Industry Connection Assets and Transformations Definitions,” 2022. [Online]. Available: https://standards.ieee.org/industry-connections/3d/bodyprocessing

[2] “Moving From 3D To A New Digital Product Creation Ecosystem.” https://www.theinterline.com/07/2022/moving-from-3d-to-a-new-digital-product-creation-ecosystem/ (accessed Sep. 02, 2022).

[3] M. MAHNIC NAGLIC, S. PETRAK, and Z. STJEPANOVIC, “Analysis of Tight Fit Clothing 3D Construction Based on Parametric and Scanned Body Models,” in *Proceedings of the 7th International Conference on 3D Body Scanning Technologies, Lugano, Switzerland, 30 Nov.-1 Dec. 2016*, Nov. 2016, no. 3011, pp. 302–313. doi: 10.15221/16.302.

[4] F. Heisey, P. Brown, and R. F. Johnson, “Three-Dimensional Pattern Drafting - Part 1: projection,” *Text. Res. J.*, vol. 60, no. 11, pp. 690–696, 1990.

[5] S. Gill and N. Chadwick, “Determination of ease allowances included in pattern construction methods,” *Int. J. Fash. Des. Technol. Educ.*, vol. 2, no. 1, pp. 23–31, 2009, doi: 10.1080/17543260903018990.

[6] S. Bogović, Z. Stjepanovič, A. Cupar, S. Jevšnik, B. Rogina-Car, and A. Rudolf, “The Use of New Technologies for the Development of Protective Clothing: Comparative Analysis of Body Dimensions of Static and Dynamic Postures and Its Application,” *Autex Res. J.*, no. January, 2018, doi: 10.1515/aut-2018-0059.

[7] S. Gill, “Improving garment fit and function through ease quantification,” *Journal of Fashion Marketing and Management*, vol. 15, no. 2. pp. 228–241, 2011. doi: 10.1108/13612021111132654.

[8] J.-H. Nam, D. H. Branson, S. P. Ashdown, H. Cao, and E. Carnrite, “Analysis of Cross Sectional Ease Values for Fit Analysis from 3D Body Scan Data Taken in Working Positions,” *Int. J. Hum. Ecol.*, vol. 12, no. 1, pp. 87–99, Jun. 2011, doi: 10.6115/ljhe.2011.12.1.87.

[9] S. Thomassey and P. Bruniaux, “A template of ease allowance for garments based on a 3D reverse methodology,” *Int. J. Ind. Ergon.*, vol. 43, no. 5, pp. 406–416, 2013, doi: 10.1016/j.ergon.2013.08.002.

[10] I. H. Kim, H. Han, and S.-J. H. Shin, “Characteristics of women’s basic bodice pattern formation in relation to the anthropometric references,” *Int. J. Cloth. Sci. Technol.*, vol. 33, no. 2, pp. 188–198, Jul. 2020, doi: 10.1108/IJCST-10-2019-0159.

[11] S. Thomassey and P. Bruniaux, “A template of ease allowance for garments based on a 3D reverse methodology,” *Int. J. Ind. Ergon.*, vol. 43, no. 5, pp. 406–416, Sep. 2013, doi: 10.1016/j.ergon.2013.08.002.

[12] R. Carufel and E. Bye, “Exploration of the body – garment relationship theory through the analysis of a sheath dress,” *Fash. Text.*, 2020, doi: 10.1186/s40691-020-0208-y.

[13] H. K. Song and S. P. Ashdown, “Development of Automated Custom-Made Pants Driven by Body Shape,” *Cloth. Text. Res. J.*, vol. 30, no. 4, pp. 315–329, Oct. 2012, doi: 10.1177/0887302X12462058.

[14] “Understanding Geometric Constraints - 2020 - DraftSight Help.” https://help.solidworks.com/2020/english/DraftSight/constraints/hlpid_constraints_geometric_basics.htm (accessed Sep. 09, 2022).

[15] S. Shimizu and M. Numao, “Constraint-based design for 3D shapes,” *Artif. Intell.*, vol. 91, no. 1, pp. 51–69, Mar. 1997, doi: 10.1016/S0004-3702(96)00057-4.

[16] V. Kuzmichev, A. Moskvin, and M. Moskvina, “Virtual Reconstruction of Historical Men’s Suit,” *Autex Res. J.*, vol. 18, no. 3, pp. 281–294, 2018, doi: 10.1515/aut-2018-0001.

[17] P. Watkins, “Garment pattern design and comfort,” in *Improving Comfort in Clothing*, G. B. T.-I. C. in C. Song, Ed. Elsevier, 2011, pp. 245–277. doi: 10.1533/9780857090645.2.245.

[18] E. BRAKE, G. KOSEL, K. ROSE, U. GRUEN, and A. RISSIEK, “Development of an Automated Product Development Process for Tailored Bras Using Breast-Specific Measurements from 3D Body Scans in Conjunction with an Interactive Pattern Construction,” in *Proceedings of 3DBODY.TECH 2020 - 11th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Online/Virtual, 17-18 November 2020*, Nov. 2020, pp. 17–18. doi: 10.15221/20.55.

[19] E. Liechty, J. Rasband, and D. Pottberg-Steineckert, *Fitting & pattern alteration : a multi-method approach to the art of style selection, fitting, and alteration*, Third Edit. New York: Fairchild Books, an imprint of Bloomsbury Publishing Inc, 2019. Accessed: Sep. 05, 2022. [Online]. Available: https://www.bloomsbury.com/ca/fitting-and-pattern-alteration-9781501318207/

[20] Joseph-Armstrong, Helen, and Ashdown, Susan, *Draping for Apparel Design*, 4th ed. Bloomsbury Publishing Plc, 2022. Accessed: Jul. 26, 2022. [Online]. Available: https://www.fairchildbooks.com/shop/draping-for-apparel-design-1

[21] C. J. Parker, S. Gill, A. Harwood, S. G. Hayes, and M. Ahmed, “A method for increasing 3D body scanning’s precision: Gryphon and consecutive scanning,” *https://doi.org/10.1080/00140139.2021.1931473*, vol. 65, no. 1, pp. 39–59, 2021, doi: 10.1080/00140139.2021.1931473.

[22] S. GILL, M. AHMED, C. J. PARKER, and S. G. HAYES, “Not All Body Scanning Measurements Are Valid: Perspectives from Pattern Practice,” no. October, pp. 43–52, 2017, doi: 10.15221/17.043.

[23] E. Gazzuolo, M. DeLong, S. Lohr, K. LaBat, and E. Bye, “Predicting garment pattern dimensions from photographic and anthropometric data,” *Appl. Ergon.*, vol. 23, no. 3, pp. 161–171, Jun. 1992, doi: 10.1016/0003-6870(92)90219-L.

[24] E. SCOTT and A. S. M. SAYEM, “Landmarking and Measuring for Critical Body Shape Analysis Targeting Garment Fit,” in *Proceedings of 3DBODY.TECH 2018 - 9th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Lugano, Switzerland, 16-17 Oct. 2018*, Oct. 2018, pp. 222–235. doi: 10.15221/18.222.

[25] N. Neagu, “Anthropic topology: an affordable approach in the study of human somatic homomorphism,” vol. 16, no. 4, pp. 360–365, 2017.

[26] M. J. Ernst, F. M. Rast, C. M. Bauer, V. L. Marcar, and J. Kool, “Determination of thoracic and lumbar spinal processes by their percentage position between C7 and the PSIS level,” *BMC Res. Notes*, vol. 6, no. 1, p. 58, 2013, doi: 10.1186/1756-0500-6-58.

[27] Y. KYOSEV and D. ZHANG, “Algorithmic Issues During the FEM Mesh Preparation of Human Models Based on 3D Body Scans,” 2020, pp. 17–18. doi: 10.15221/20.48.

[28] D. HARRISON, Y. FAN, E. LARIONOV, and D. K. PAI, “Fitting Close-to-Body Garments with 3D Soft Body Avatars,” pp. 184–189, 2018, doi: 10.15221/18.184.

[29] E. D. Demaine and M. L. Demaine, “Recent results in computational origami,” *Origami*, pp. 3–16, 2002, doi: 10.1201/b15735-3.

[30] S. P. Ashdown, M. Sung Choi, and E. Milke, “Automated side-seam placement from 3D body scan data,” *Int. J. Cloth. Sci. Technol.*, vol. 20, no. 4, pp. 199–213, 2008, doi: 10.1108/09556220810878829.

[31] A. R. G. Harwood, J. Gill, and S. Gill, “JBlockCreator: An open source, pattern drafting framework to facilitate the automated manufacture of made-to-measure clothing,” *SoftwareX*, vol. 11, no. December 2019, p. 100365, Jan. 2020, doi: 10.1016/j.softx.2019.100365.

[32] X. Peng and V. E. Kuzmichev, “Virtual method of predicting the accuracy of pattern blocks,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 459, no. 1, p. 012084, Dec. 2018, doi: 10.1088/1757-899X/459/1/012084.

[33] J. Yan and V. E. Kuzmichev, “A virtual e-bespoke men’s shirt based on new body measurements and method of pattern drafting,” *Text. Res. J.*, vol. 90, no. 19–20, pp. 2223–2244, 2020, doi: 10.1177/0040517520913347.

[34] W. Lee and H. S. Ko, “Heuristic misfit reduction: A programmable approach for 3D garment fit customization,” *Comput. Graph.*, vol. 71, pp. 1–13, Apr. 2018, doi: 10.1016/j.cag.2017.10.004.

[35] “Undefined: The Missed Potential Of Digital Product Creation.” https://www.theinterline.com/04/2022/fashion-3d-tech-pack/ (accessed Sep. 05, 2022).

[36] E. Scott, S. Gill, and C. McDonald, “Novel Methods to Drive Pattern Engineering Through and For Enhanced Use of 3D Technologies,” 2019.

[37] S. P. Ashdown and M. DeLong, “Perception testing of apparel ease variation,” *Appl. Ergon.*, vol. 26, no. 1, pp. 47–54, 1995, doi: 10.1016/0003-6870(95)95750-T.

[38] E. L. Scott, “The role of 3D measurement technology and anthropometric data for improved garment fit and sustainable manufacturing,” *Digit. Manuf. Technol. Sustain. Anthr. Appar.*, pp. 23–48, Jan. 2022, doi: 10.1016/B978-0-12-823969-8.00002-2.