Landmarking and Measuring for Critical Body Shape Analysis Targeting Garment Fit

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Abstract

Industry 4.0 points to manufacturing that embraces both automation and customization yet apparel industries continue to be inhibited by the necessity for trial-and-error fittings to correct garment fit and while 3D technologies have gone far to automate fitting workflows, an inability to quantify body shape continues to plague automation integration. This paper explains why traditional methods of relating anthropometry to a 2D pattern are the root cause of poor garment fit and presents a solution for mathematically quantifying both body shape and garment fit. With an eye towards mass garment customization, and the theory that any pattern should be customizable for any human shape, theories on the relationship of 1D anthropometry and 2D block pattern were continuously re-trialed and honed over a thirty-year bespoke garment design/patter-making career. The methods presented were developed by combining common practices of triangulated pattern development with fabric draping and origami. A novel method of pattern block making was developed and found to be effective for accurate replication of body shape. Testing of the Clone Block™ proved successful for both men and women of a variety of sizes, making it gender neutral and well suited to automation. Landmarking and measuring requirements are mostly within the boundaries of ISO standards with a few novel requirements. While time intensive for hand measuring, the process is well suited for scanned measurement data and virtual environments. The Clone Block ™ offers a critical assessment of body shape for automated garment fit, improved virtual size selection, more realistic virtual fittings, the optimizing of twin avatars to clones, and mass garment customization.

Keywords: Clone Block, Mass Customization, Body Shape, Garment Fit

1 Introduction to Automated Fit Problems

Industry 4.0 points to manufacturing that embraces both automated production and product customization and while the technological platforms for these production models exist, integration of these technologies into apparel manufacturing has been slow [1, 2, 3]. Made-to-measure (MTM) Computer Automated Design (CAD) platforms fail to satisfactorily fit outlier body types and require further fittings to perfect fit [4, 5, 6]. Virtual fitting platforms curate size selections that fail customer approval [7] Automated sizing platforms provide environments to simulate virtual try-on but offer an approximation of fit often far from reality [8, 9]. Varied reasons have been cited as problematic, with fit preference (desired garment/pattern dimensions exceeding body dimensions) being noted as the most complicated and problematic aspect of garment fit [10]. Fit preference, or ease (objectively measureable garment/pattern dimensions exceeding body dimensions), is a complicated topic because of its subjective nature [11, 12]. If we accept garment fit to be objectively measurable body dimensions plus a subjective, yet measurable, amount of ease, we can see that garment fit is mathematically calculable. While discussion of the subjective topic of fit preference (ease) is critical for assessing garment fit, this paper intends to highlight that the data required for such a discussion is not yet even available due to a missing variable; quantifiable body shape. With correct data regarding body shape, analysis regarding fit preference is provided the rigour required to address garment fit. To that end, this paper will discuss landmarking and measuring methods for directly relating body shape to a 2D Clone Block™ for quantifiable body shape [13, 14].

1.1 Body Shape

The apparel industry has directed much effort towards understanding body shape and while methods for effective classification of visual body shape are available [14, 15, 16, 17], they are limited in that they do not directly affect pattern engineering or garment fit [18, 19, 20, 21, 12]. This is partly because the eye can be deceived with regard to shape, as illustrated in Figure 1. Body shape, as related to a frontal observation of a person, should not be confused with morphology. While both are quantifiable, visual body shape is mostly illusion while body shape morphology directly affects pattern shape and garment fit. Figure 2 illustrates how body shape may be revealed on a pattern, which is in striking contrast with graded pattern development that simply resizes pattern length and girth dimensions around the same inherent darting and shaping. Traditional methods of shape analysis fail to directly relate body shape to 2D pattern-making making [22, 21].

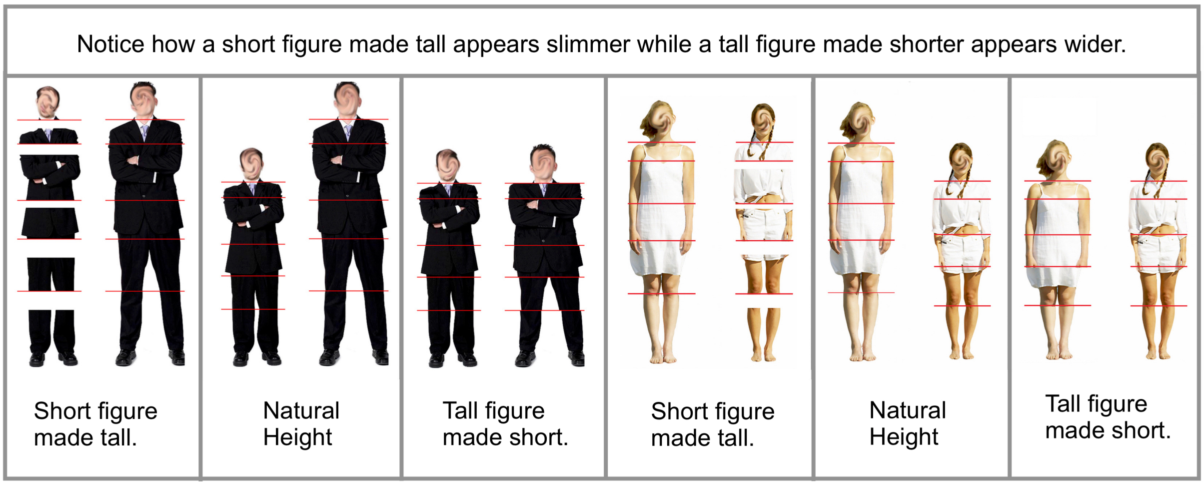


Figure 1 – The illusion of body shape can be distorted by height.

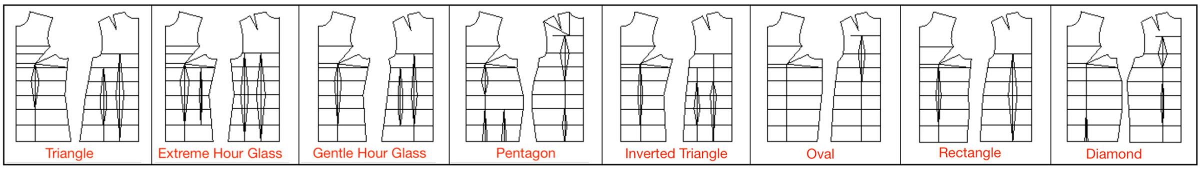


Figure 2 – Improved garment fit must view body shape from a 2D perspective.

1.2 Ease

Using traditional methods for fitting bodies, it would appear that body morphology can only be addressed with garment fittings and, in fact, common pattern engineering practices support this. Textbooks on drafting garment blocks offer instructions for development followed by post development methods to perfect pattern fit, with a test garment try-on and subsequent pattern amendments [23, 24, 25, 26, 27, 28, 29, 30, 31]. This suggests the inventors of such methodologies understood the limitations of their approach and that traditional drafting methods are, more or less, simply approximations of body morphology with true shape reliant on fittings [5, 32].

This is partly due to the fact that these methodologies do not numerically isolate ease, inhibiting the comparison between 3D body shape and 2D pattern dimensions [11], and partly due to a lack of 2D understanding of body shape, demonstrated by the variety of pattern shapes produced for base pattern blocks using different pattern engineering methods [11, 33, 34, 35].

Having been built on pattern shaping and fitting methodologies known to not isolate body shape, it seems inevitable that the virtual apparel world would inherit the fitting problems of the physical world; garments offering satisfactory fit to only a small segment of the population.

3D technologies have gone far to automate the workflow of fittings [36] but without an ability to quantify body shape the full potential of virtual sampling is not realized, as virtual fittings can offer no more than the same aesthetic perspective on garment fit available with physical fittings. Critical assessment of garment fit requires quantification of both body shape and ease and research has demonstrated the potential of virtual garment design when these criteria can be isolated. Methods of creating a pattern block by flattening body shape [37] from a 3D model have successfully been trialed. Methods of removing and flattening an onion layer surface from a 3D model have offered proof of concept of the bespoke fit achieved with a block that suitably clones body contours, but the shapes resulting from the flattened mesh do not adhere to the principles of fabric grain and dart manipulation essential for apparel pattern development [38, 39, 20].

Traditional methods of shaping garments to bodies rely on standardized darting and shaping [37] with an understanding that bespoke fit is achieved with “nipping and tucking” during physical garment fittings. [32] Only a few authors make any attempt to quantify shaping and those that do fail to provide a consistent mathematical basis [25, 27, 23, 40]. With the goal of improved garment fit, methods to replicate the nipping and tucking of bespoke fittings must be accounted for in measuring and pattern engineering practices. For this to be possible, body morphology must precisely be accounted for and a mathematical basis for darting and shaping provided.

1.3 Landmarks

Key to the relationship between anthropometry and morphology are the foundational landmark points from which the principles of triangulation are used to measure and map the body. Manually locating landmarks is challenging due to difficulties discerning between skeletal points and body flesh [41, 42, 43, 44, 45, 46, 47]. Body scanning has an advantage over manual landmarking in that the body is mapped in its entirety, and any point may be assigned and extracted. Correlating inconsistent [44] manual landmarks with scanned landmarks has, however, proven difficult [48, 49, 50, 51] and combinations of the two are often combined [52]. Since these points reflect key pattern triangulation points of reference for body shape analysis, errors can quickly have negative compounding effects, skewing data analysis, causing incorrect size selection, and impeding morphological assessment. Further problems exist due to the non-static and ambiguous nature of industry standard landmark and measuring points. Industry standards for acquiring body anthropometry [53, 54, 55, 56] often produce incongruent results not compatible for cross-disciplinary use. The breast apex, dependent on its supporting structure, is variable and a non-static point of reference [46]. User interpretation of standards makes reliable tracking of measurements through weight fluctuations difficult, thereby inhibiting relative comparisons [57, 58].Conflicting methods of interpreting anthropometry impedes waist-to-hip ratio assessment [59] and leaves room for substantial interpretation and discrepancies making data between brands incompatible [42, 45, 43, 60]. Variations in methods of body segmentation for anthropometric assessment [52, 61, 62, 63, 64, 65] do not necessarily correlate to logical pattern engineering landmarks. Methods for taking arc (half body) measurements [53, 21] produce further inconsistencies due to how side seams are assigned [11, 21, 66, 41].

Traditional pattern drafting methodologies cannot produce a suitable fit on all body shapes [67, 68, 20, 34, 22]. It has been speculated that a mathematical method of quantifying body shape could provide the objective means to discern garment fit without the need for a physical fitting thereby facilitating the automation of fit. [69] The fact that garment design is founded on gender specific pattern drafting methods [25, 24, 27, 23] speaks to a lack of methodology for assessing body morphology from anthropometry. A thorough understanding of how anthropometry translates to morphology would make it possible to fit any pattern to any shape of body, regardless of gender. Our current methodologies for shaping patterns (and fabric) to bodies, while suitable for the heuristic practices of the artist, lack a mathematical relationship to human form [70] suitable for computer automation of garment fit. To that end, this paper discusses landmarking and measuring for critical body shape analysis and presents the Clone Block™ as a mathematical quantification of body shape to replace the use of 1D measurements for assessment of garment fit.

2 Methods

The discussed landmarking and measuring practices meld techniques of hand draped bespoke fitting, traditional triangulated block pattern development, origami, and with the following guiding principles.

1. Methodologies must support the premise that it is possible to fit any garment to any body shape with correct data analysis and that poor fit identifies poor data analysis.
2. Garment fit is defined as body dimensions plus ease, which can could further be broken down for understanding, and it therefore mathematically quantifiable for 2D representation.
3. Anthropometric analysis was approached from the perspective that landmarking and measuring methods will be gender and age neutral toward the goal of automated garment pattern customization based on body scanned measurement data.
4. Landmarking and measuring will be from static points of reference for effective comparison of changes to body shape. (i.e. change in breast supporting structure, maternity, compression, weight gain, degenerative diseases, cosmetic surgery, aging)
5. Principles of origami will be used to solve areas of measurement discrepancy for 2D mapping of the body and darting and shaping will therefore be mathematically calculable.
6. 2D mapping will consider the whole body (in opposition to traditional methods that consider upper body and lower body independent of each other) and shaping and darting will be directed so as to keep fabric grain vertical and horizontal around the entire body.
7. The resulting block will be congruent with common methods of dart manipulation significant in the garment design and pattern-making process.
8. The side seams will be considered dart locations but center front and center back lines will not be used for shaping.

2.1 Shaping Principles

Darting is common to all close-fitting block development processes but only a few use any sort of logic as to relationship between dart size and anthropometry. [67] Consequently, it was necessary to redefine the use and quantification of darting as part of the methodology for mathematically defining body shape. To that end, it is useful to consider fabric darts with reference to origami as illustrated in Figure 3.

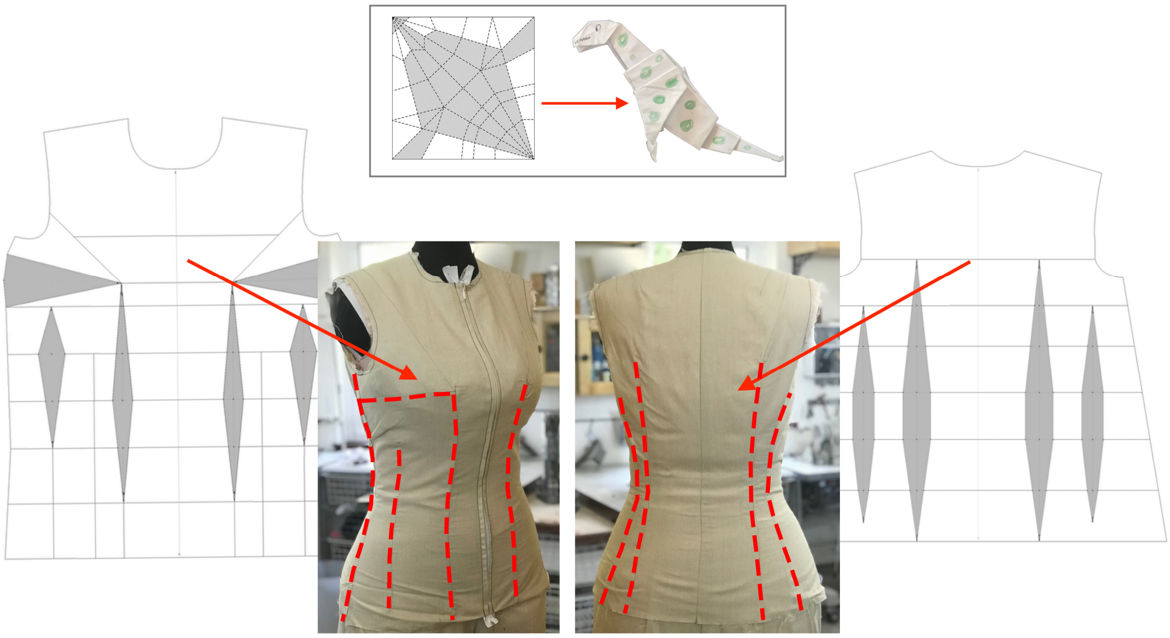


Figure 3 – The relationship of origami to pattern-making.

When a piece of paper is folded to create a 3D shape, there is paper hidden within the design. As illustrated by the grey zones, garment pattern fitting darts are similar to the hidden areas in origami. They are essential to the structure but not necessarily a visible part of the design. Removing (or not folding out) one of the grey areas in the T-Rex origami shape would destroy the shape. Comparably, not sewing one of the grey zone darting areas in the garment pattern would destroy the body shape that the 2D pattern is attempting to mimic. Fit is destroyed when shaping is not compatible to the body morphology beneath it. This is not to say that all designs require internal darting but it does highlight the need for quantification of shaping.

Fabric draping (hand forming fabric to body shape) was frequently used in the research process to aid in choosing static anthropometric points of reference for positioning darting and shaping while maintaining fabric grain. Figure 4 illustrates the basics of darting from an origami perspective.

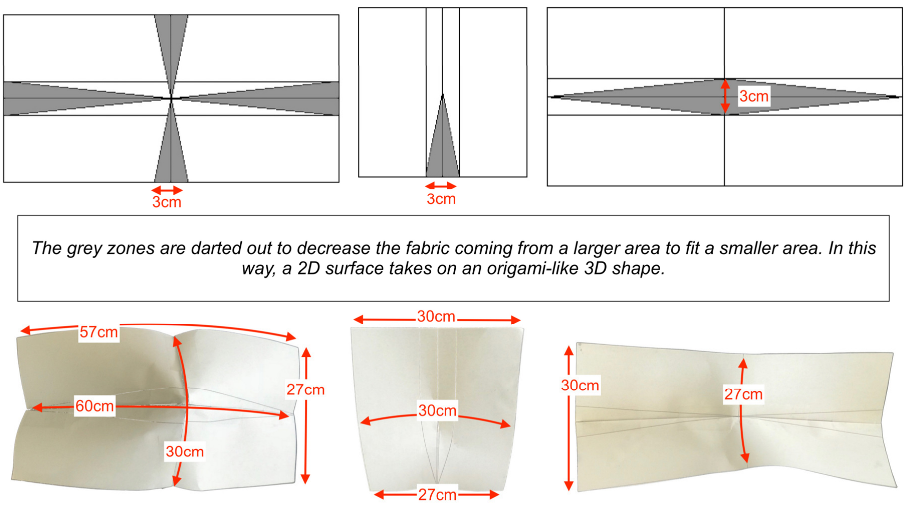


Figure 4 - Basics of darting from an origami perspective.

Fundamental to garment design is the principle of dart manipulation from a static apex point of reference, permitting shaping such as bust fitting darts to be relocated suitable for a given design. [25, 23, 27] Since relocation possibilities of fitting darts are as infinite as design possibilities, it was necessary to consider a base point of reference from which shaping for a global population would be constant. Three significant shifts in body shape assessment were required:

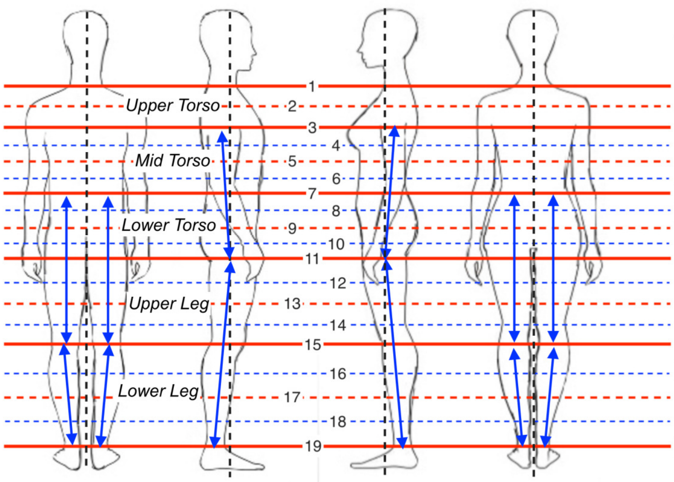
1. Critical body shape assessment requires a substantial increase in the number of landmark lines required, which aligns with concerns of other researchers eluding to the need for an expanded measurement list (beyond the basic bust/ waist/ hip) for accuracy in discerning body morphology [34, 42, 45, 71, 60, 72, 61].
2. Body segmentation is keyed to critical areas where anthropometric study has revealed lengths affecting height occur. The most notable changes are to the definitions of mid and lower torsos.
3. The use of half body dimensions from a true side seam (used to differentiate a side seam for identifying body morphology from a garment seam positioned as per subjective design aesthetic) is used in lieu of the more common full body girths.

2.2 Measuring and Mapping the Body

As illustrated in Figure 5, the body is segmented vertically into quarters and horizontally into five main areas, which are further proportionally sub-divided for static landmark locations. While there are numerous ways to analyze body length proportions, this methodology effectively balances concerns for pattern engineering with weight distribution areas known to effect shape and posture. Quarter division of the body from front to back (commonly referred to as princess lines) is correlated to a measurable leg stance measurement (caliper center of knee to caliper center of high thigh). Half body division is accomplished with careful placement of a true side seam running from the center of the armscye (caliper center of biceps located on the highbust line), to a high-thigh point (caliper thickness of the high-thigh on the side of the body and aligned with back crotch depth), to the ankle bone apex and extending to the floor.

There is disparity with regard to precise placement of the side seam as indicated by the numerous ways in which the upper body side seam has traditionally be located [41, 67, 71, 72, 61, 73, 66]. When we consider connecting the upper and lower body segments, however, there is less room for discussion. To account for individuals where the high thigh girth is larger than hip girth, side seam location is directed by the more difficult thigh fitting area. This also correlates with the tendency for front thigh to be larger than back. Using the caliper thickness of the thigh allows the torso and leg patterns to more effectively be connected while still adequately permitting for a variety of body morphologies and encouraging the best compromise between weight distribution of the upper and lower body.

To minimize data redundancy, and maximize data usage across many fields, universal methods of segmenting the body for body height assessment are required. Key landmarks such as the bust, waist and hip require static locations not prone to interpretation. By dividing the body into five main easily landmarked segments, which are further proportionally sub-divided, the body can be assigned static landmarks against which accurate mapping may occur and natural changes to weight and height observed.



Clone Block™ Landmark Lines		Compatible ISO 8559-1:2017 Girth Measurements	
1	Highchest	5.4.4	Across back width
2	Highchest	5.4.7	Across front width
3	Highbust	5.3.6	Chest Girth
4	Bust	5.3.4	Bust Girth
5	Ribcage	5.3.9	Midriff Girth
6	Highwaist	5.3.10	Waist Girth
7	Lowaist	5.3.11	Upper hip girth
8	Abdomen	5.3.12	Top hip girth
9	High Hip	5.3.13	Hip girth
10	Low Hip		NA
11	High Thigh Body Girth	5.3.14	Maximum Hip Girth
12	High Thigh	5.3.20	Thigh girth
13	Mid Thigh	5.3.21	Mid-thigh girth
14	Low Thigh		NA
15	Knee	5.3.22	Knee girth
16	Low Knee/ High Calf		NA
17	Mid Calf	5.3.24	Calf girth
18	Low Calf		NA
19	Ankle	5.3.26	Ankle girth

Figure 5 – Body segmentation for critical body shape analysis.

A whole-body approach is taken to directly relate 1D measurements to 2D. In contrast with traditional industry pattern development approaches of drafting the upper and lower body segments individually, block development is done from the point of view of a jumpsuit. Body lengths and girths are mapped according to the draping principles of the greatest length or girth and appropriately darted to keep fabric on-grain (using the principles of origami-like darting illustrated earlier). Fabric draping [74] (hand forming fabric to body shape) was frequently used in the research process to aid in choosing static anthropometric points of reference for positioning daring and shaping while maintaining fabric grain. A golden rule for fabric draping is that the largest girth measurement of the body area being draped must first be accommodated before considering how to adjust fabric for the smaller areas. Then, to reduce the volume of fabric coming from the larger area to fit the smaller area, fabric is reduced through darting, which hides fabric in its creases, and seamlines, which eliminate otherwise hidden areas. Figure 4 Illustrates the basics of darting from an origami perspective. The method for mapping the body in 2D is broken into three steps illustrated in Figure 6: mapping the vertical landmarks pertinent to body lengths, mapping the horizontal landmarks pertinent to girth measurements, and configuring the grey zone darting and shaping using an origami-like approach illustrated in Figure 4.

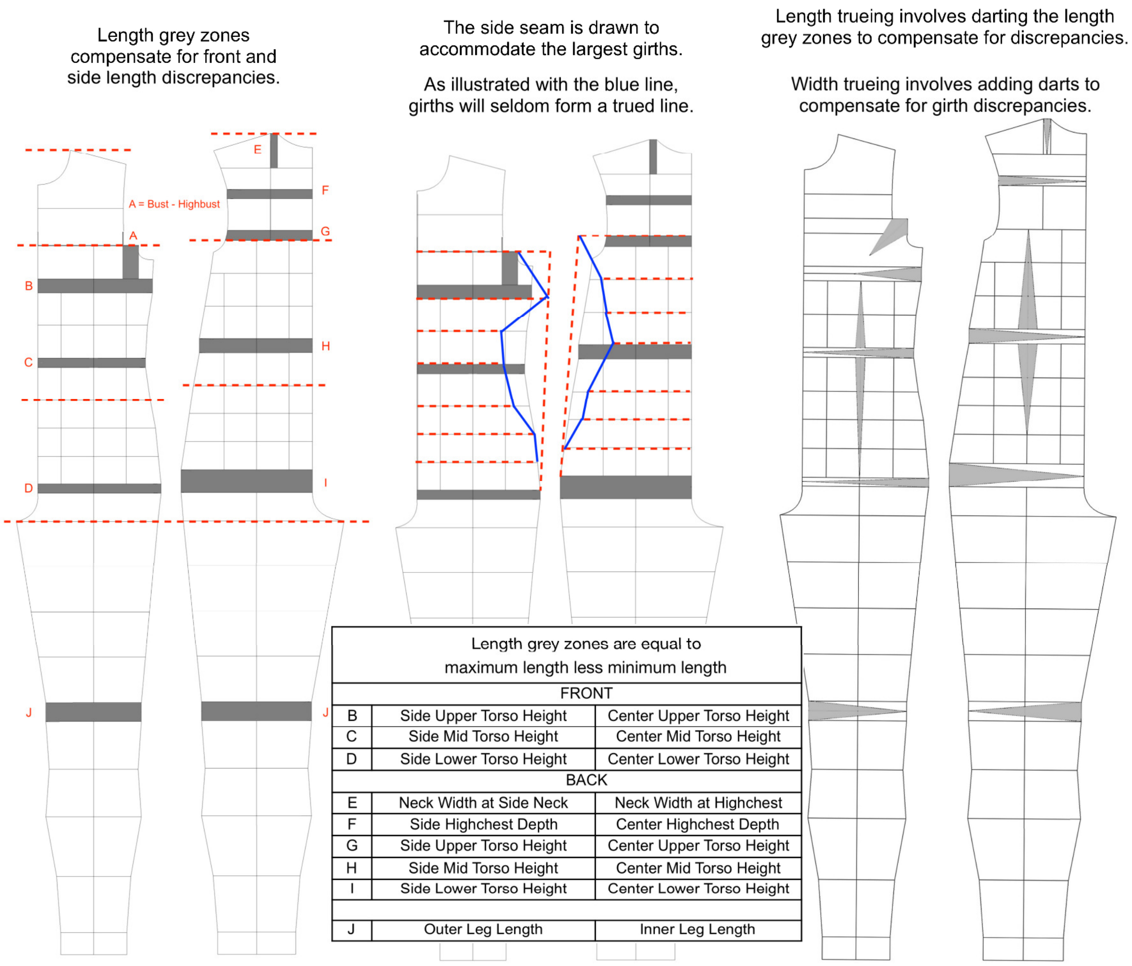


Figure 6 –Mapping the Clone Block™ and using origami grey zones (darting) to solve measuring discrepancies.

2.3 Testing

Methods to directly relate anthropometry to a block pattern, using the above principles, were practically tested in a bespoke bridal and eveningwear manufacturing environment over a career spanning three decades. It was necessary to develop methods to add appropriate ease to the Clone Block™ because base garment ease is required to permit sufficient body movement for test fitting. This ease methodology served to perfect shaping methods within a bespoke manufacturing site. Further beta testing of the Clone Block™, without ease, was accomplished by either pin-fitting or taping pattern pieces to the subject. Seamed pieces were used whenever possible.

Techniques were finessed through extensive trial-and-error fitting. If a pattern was found to require "nipping and tucking" or "the pinning out" of excess fabric it was assumed that analysis of anthropometric data had been incorrect. Garment fit concerns were assessed with regard to fabric grain and how variations on measuring could have prevented the concern. Subsequently, the resulting pattern would be reverse engineered until the correction could be traced to a definitive missing (or occasionally incorrect) measurement. To create the block, only linear measurements (1D) with a direct correlation to a block pattern (2D) were used. This is in stark contrast to traditional methods of block pattern generation where portions of the block (i.e. bust shaping dart and waist darts) are suggested for use without mathematical reason. Numerous varieties of 1D-to 2D relationships were tested and re-tested until a method of directly relating body measurements to a base pattern was found to produce a suitable fit. The compounding effects of shaping from one area affecting another changed the hierarchical order of fit many times. Further testing in a MTM bridal and eveningwear manufacturing environment revealed the methods effective, provided breast support did not change. A subsequent study of breast sizing addressed the fitting obstacles encountered with a change in breast support.

The 2D accommodation of the non-developable breast mounds yet again changed the hierarchical order of fit but also permitted the methodology to be congruent with both male and female bodies. Further anthropometric research on athletes with highly muscled thighs led to a repositioning of the side seam landmark points, improved pant fit and facilitated the joining of the upper and lower body blocks. This finding also provided key information regarding leg split placement which had been problematic. Although this was not one of the foundational principles, it became apparent during bespoke suit manufacturing that a correlation between the torso and pant blocks would be inevitable for automation.

3 Results

Much of the development of this block involved the inclusion of ease to allow for the natural difficulties with fitting a body in a dynamic state (i.e. chest expansion with breathing, compression and contraction of the body with movement). From this perspective, and the satisfaction of the clients, this automated method of identifying body shape is considered successful. Testing the fit of the block without ease proved difficult as the block could only partially be sewn frequently requiring pin-fitting and sticking block panels to bodies. While successful on average build bodies, the fitting method was difficult to test on heavy set and senior figures due to mobility issues requiring more ease. Although a block with minimal ease was successful in fitting this group, further study with this group is warranted. To that end, an application has been developed to automate the development of the block. Testing the effectiveness of these methods at ascertaining body shape on figures with conditions known to distort shape from what is considered average is also warranted. (i.e. dowager's hump, bow legs, buffalo neck, scoliosis, etc.) While case studies on outlier figures were conducted successfully, research with reference to a global population must be ongoing. A preliminary further study using CLO software proved unsuccessful due to an inability to adjust avatars to reflect the shapes of the previously discussed research group. This exploration, however, demonstrated the potential of such software for supporting mass garment customized production models.

The methodologies presented build on established garment industry practices to produce significant pattern fit improvement while minimizing changes to common workflows. As illustrated in Figure 5, The required measurements are not so different from traditional practices as to be unfamiliar to pattern technicians or incongruent with product development practices. From a pattern-making perspective, the Clone Block^{TM}, at first glance, can appear unfamiliar. As can be seen in Figure 7, however, applying common principles of dart manipulation soon transforms the block into familiar shapes but this time with mathematical rigour (found in the reconciling of width and length incongruences in Figure 6) behind darting and shaping to support body shape.

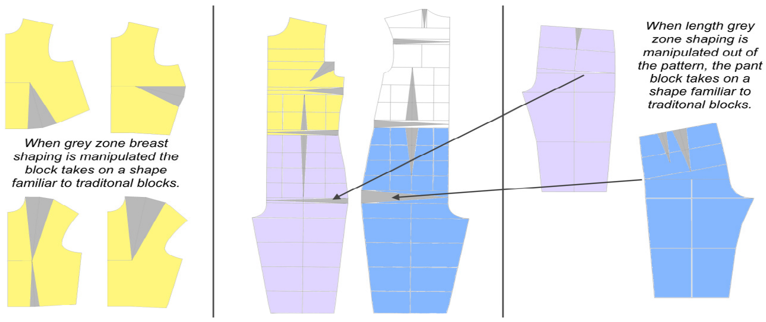


Figure 7 – Dart manipulation moves the origami-like darting to positions familiar to traditional shaping practices.

The shaping methodologies behind the Clone Block^{TM} provide the direct body to pattern correlation that has been inhibitive to garment fit customization. [75] [76] [41] The number of measurements required to discern body shape is strikingly large, requiring a minimum of sixty minutes of hand measuring, but rapidly evolving body scanning technology [77] alleviates the time constraints that could make these methods impractical.

3.1 Discussion

It is useful to consider the fit of traditional garment blocks with reference to ISO standards defining 3D avatars [78]; Twin avatars reflect a 3D model approximating body shape while clone avatars indicate a 3D model mirroring body shape. Similarly, traditional pattern-making methods produce a twin block, while the methodologies presented herein produce a Clone Block^{TM}. Twin block (traditional) methods of drafting garment blocks can only offer an approximation of the human body because the shaping inherent in the pattern is directed at a singular body shape, requiring trial-and-error fittings to adjust the block suitable for bespoke pattern-making. The Clone Block^{TM} offers a method of directly relating 1D body measurements to 2D block thereby mirroring body shape without the need for shape correcting fittings. While both methods can achieve the same result, use of the twin block requires substantial operator intervention thereby disrupting the automation process.

The inherent fit of a block remains directed by the shaping it was derived from. Attempting to fine tune body shape into a twin block is somewhat similar to trying to turn a T-rex shape into a duck. It can be done, but it may require reworking the whole design. Figure 8 illustrates the difficulty with adjusting twin blocks for a clone fit. Grey zone shaping is unique to a body. While a graded pattern can sufficiently accommodate girth and length requirements, nuances that define body shape are more difficult to accommodate through a garment or pattern alteration process.

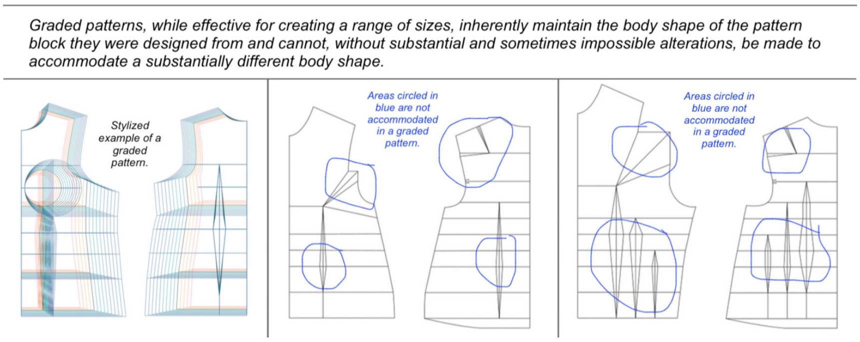


Figure 8 - Grading for body shape is not possible.

This is why garments, directed at body shape groups, can offer slightly better fit than traditionally sized product lines; brands targeting body shapes have blocks with different inherent body shape profiles specific to different fit models [79]. They have identified the 2D body shape profile of a given demographic and developed a block specific to that shape group. Figure 9 illustrates mid torso shaping from a variety of patterns for different body shapes hinting at why complaints regarding ready-to-wear exist; it is simply not possible that a single sizing system (developed from a single body shape profile) could grade to accommodate even this limited range of shapes, let alone an entire global population. Body shape cannot be graded for.

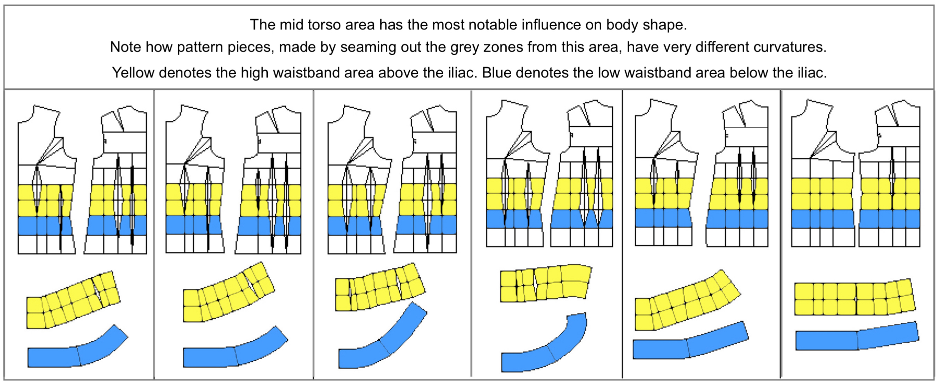


Figure 9 - Bespoke mid-torso shaping possible with the Clone Block^{TM}.

3.2 Ease

While a detailed discussion on ease is outside the scope of this paper, it is CRITICAL to understand the role darting and shaping play in garment ease. Without this understanding, it is easy to discount the inherent role the body shaping requirements of a figure play in garment design. A garment block reflects the body shape of a fit model. During the design process this block is manipulated, as per common practices [24, 25, 29, 27], into the chosen garment pattern. Most garment designs, are not as close fitting as the pattern block discussed herein, are often void of darting, and have an amount of ease added. Often, unused darting and shaping becomes ease. The blocks in Figure 10 have been converted to patterns with 24cm of waist ease. Part of this ease was gained by leaving internal darts unsewn and the rest was added at the side seam. Note how the center pattern required the addition of much more girth to the side seam than the other patterns due to the associated 2D body shape requiring minimal internal darting.

Just as the 3D design of the origami T-rex would be changed if a grey zone was left unfolded, so too is a block changed when the darting grey zones, required for the 2D body shape, are left unsewn. Doing so is not incorrect, in fact it is a natural part of the design process, however, not mathematically accounting for it is where traditional methods of garment fit assessment offer poor data analysis.

Garment fitting parameters change with varying levels of garment ease, and frequently, the body shape requirements of a given figure are translated to garment ease and therefore not visible. The importance of identifying this shaping HIDDEN within ease remains a crucial, mostly overlooked, factor negatively effecting the ability to correctly assess garment fit. As illustrated in Figure 10, body shape dictates the amount of hidden ease available as it directly relates to shaping and truing (the process by which seams, lines and curves are smoothed to make a pattern production ready) of the pattern during the design process.

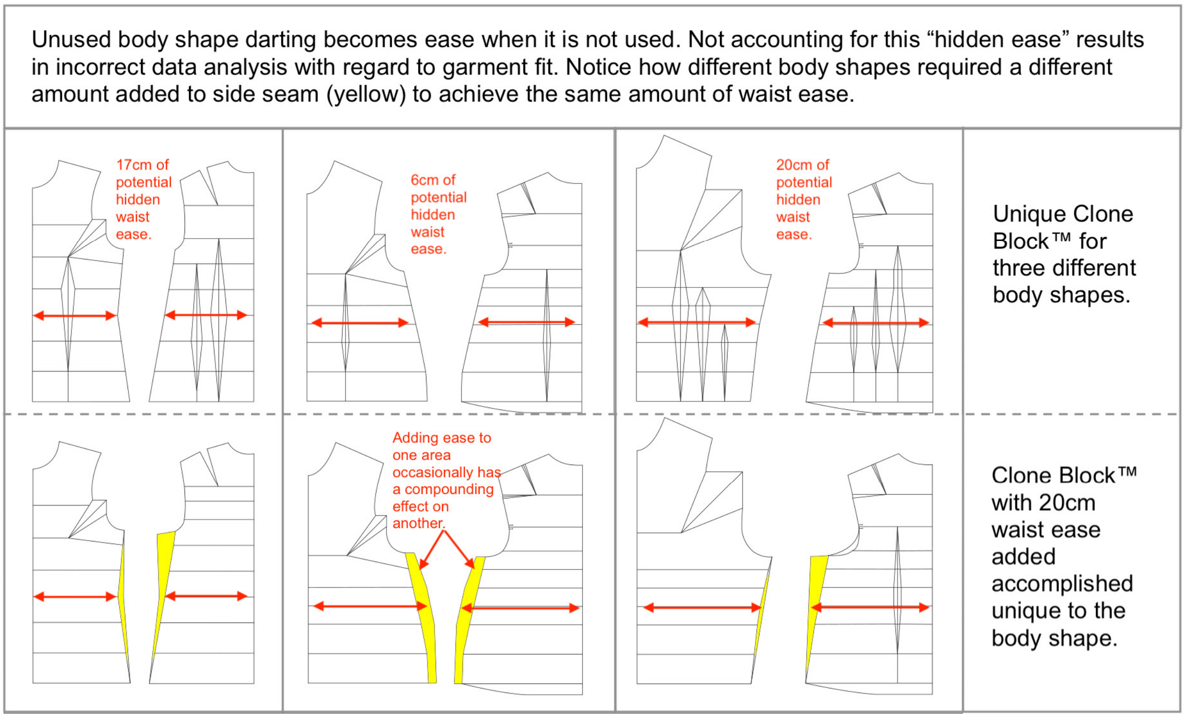


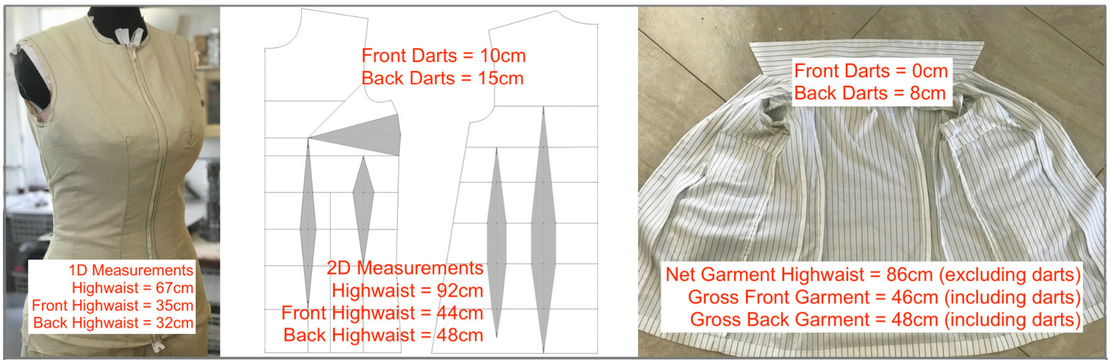
Figure 10 – The effect of body shape on ease and garment fit.

3.3 Quantifying Garment Fit

Regardless of whether a design requires the aesthetic of a close fit, the inherent shaping of the block cannot be dismissed and unused darting must cleverly be manipulated into the design. This is a guiding principle of garment design taught early in pattern-making training. As the apparel industry embraces mass garment customization, methods to change the inherent block shape must therefore be developed. Incorporating Clone Block^{TM} landmarking is a first step towards this goal. Automation of fit can only happen from static points of reference correlated to 3D body and garment. Without a direct relationship between garment and body, fit can never be automated or controlled without visual manipulation.

Garment fit is an admittedly elusory term prone to interpretation but it can be agreed upon that it involves judging how garment material interacts with the body. From this understanding, and with both body and garment dimensions quantified garment fit becomes a simple equation. A mathematical understanding of where a body requires shaping provides a means by which to quantify the subjective judgement of material to body interaction. 2D body shape dimensions permit a critical assessment of garment fit while not infringing on the subjective opinion of fit. In this regard, the usefulness of the Clone Block™ extends beyond the creation of a garment pattern.

When assessing garment fit, it is the 2D dimensions of the Clone Block™ that are of concern. Traditional methods of using 1D measurements for garment fit assessment produce substandard results because they fail to critically assess body shape. While the subject of fit preference and garment ease is outside the scope of this paper, the methodologies within offer a platform from which the controversial discussion of ease [11, 80] and garment fit may begin. As illustrated in Figure 11, without body shape quantified, it is not even possible to separate ease from garment dimensions for critical discussion. While the assessment of ease in Figure 11 is the same with both a traditional and bespoke assessment, a Clone Block™ assessment provides better a more thorough analysis of the body to garment interaction.



TRADITIONAL GARMENT FIT ASSESSMENT - provides potential incorrect data analysis:

86 (Net Garment Highwaist) - 67 (1D Highwaist) = 19cm ease

Clone Block™ GARMENT FIT ASSESSMENT - provides sufficient data for correct analysis:

FRONT: 46 (Gross Garment) - 44 (2D Highwaist) = 2cm extra ease + 10cm hidden ease = 12 cm total ease

BACK: 48 (Gross Garment) - 48 (2D Highwaist) = 0cm ease + 15 (hidden ease) - 8 (garment darts) = 7cm ease

Figure 11 - Quantifying garment fit and isolating fit preference.

4 Conclusion

Technologies to support the apparel industry's transition to fully automated product customization have demonstrated great potential for mass garment customization [81, 82, 38, 83], but our methodologies for quantifying body shape and garment fit are inhibiting automated garment fit [84]. While landmarking and measuring is admittedly a first step in a multi-step process toward mass garment customization, it's direct relationship to the Clone Block™ is foundational towards the required methodologies. Combined with proven automation platforms the Clone Block™ could further facilitate the apparel industry's integration into Industry 4.0. Without a global standard for mathematically defining body shape, automated size prediction applications and customized fitting platforms will continue to struggle with data analysis. [85] The ability to quantify body shape allows for the isolation of garment ease and an objective discussion on the subjective topic of garment fit [69, 33, 37].

With body morphology being important to the fields of apparel, 3D modelling, ergonomic design, medicine, 3D modelling, body scanning, health and fitness, and garment sizing, further study should consider the implications and cross-disciplinary use of the Clone Block™.

Only when our methodologies catch up to our technologies will effective automated fit, virtual fittings and mass garment customization be possible.

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