Knit to fit: applying technology to larger-sized women's body shapes

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Introduction

This research aims to achieve a better understanding of fully fashioned weft knitting related to larger, individual, 3D bodies. By developing knitting processes using a widely available Shima Seiki flat bed machine, accessible and transferable results have been produced. It challenges the universality of the size 12, hourglass figure, which has been disproved by SizeUK findings, and the apparent horror of fat which is demonstrated from haute couture to the high street (Shabi, 2004, p. 26; Allen et al., 2004, p. 1).

Through personal experience, I became increasingly aware of the frustration and potential humiliation women experience when seeking well-fitting clothing in the high street; a phenomenon also recognised and reported in the media (Shabi, 2004, p. 25–28). This insight, combined with experience in knitwear design and computer-aided design and manufacture (CAD/CAM) skills, formed the core of my research. CAD/CAM offers flexible design for individual variables, and utilising these interdisciplinary skills on converging pathways makes this research unique in knitting.

3D shaped garments have been developed to fit the individual body shape of a cohort of women over UK size 16. These prototypes may contribute towards custom-made production similar to that of the envisaged scenario 'Driving Miss Daisy', in which customers can upload 3D body scanned measurements via smart cards, try on products virtually, select materials, colours, styles etc. online, and receive their goods within a few days (European Monitoring Centre on Change, 2005–06, pp. 18–22).

Participants are encouraged to make suggestions to aid evaluating and remaking garments they will find more comfortable and wearable. An online, multiple-choice survey has yielded informative, anecdotal evidence, whilst Trinny and Susannah's Body Shapes Survey, and Gok Wan's *How to Look Good Naked*, are indicative of parallel public interest in the subject. (Woodall & Constantine, 2007; Wan, 2007.

Background

Ageing changes body shape; these changes were catalogued during Professor Susan Ashdown's research at Cornell University into older women's clothing. Ashdown also found that 92% of older women have difficulty finding well-fitting clothes (Lang, 1996). This is, however, not exclusive to ageing; Abbot and Sapsford write that female teenagers over a size 14, 'find it difficult if not impossible to purchase the clothing that is seen as fashionable, and are thus … excluded from teenage fashion' (Abbott & Sapsford, 2001, p. 25).

The 2003 national survey SizeUK found the average woman to be a size 16, and Size USA showed a similar trend in 2004 (Sorkin, 2004, p. 1). Paradoxically, women of size 16 and above find clothes shopping fruitless and frustrating. This research addresses these related phenomena in the context of knitwear.

A significant finding is that larger women may look to custom-made clothing. 9% of the 309 respondents to an online survey already buy or make custom clothing and 80% would consider this option; of the remainder, 7% replied that they would never do so and 4% abstained.

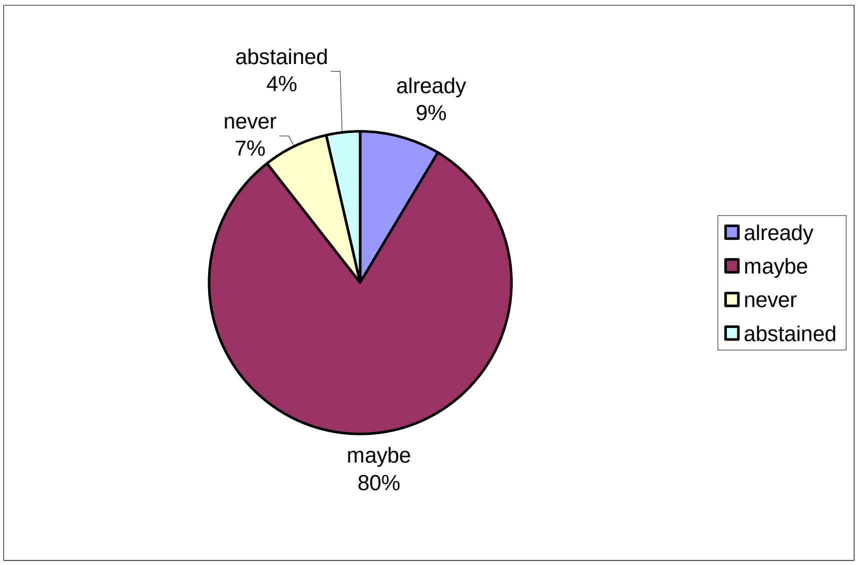

Figure 1: Pie chart illustrating the percentage use of custom clothing amongst 309 survey respondents

The main interest in custom clothing remains in traditional tailoring. Brooks Brothers in New York started scanning in 2002, with Benchmark Clothing starting in 2004; custom jeans have also been pioneered by Bodymetrics. ([TC]2, 2004) (Cohen, 2004)

Scanning and clothing

Interpreting body scan data into 2D patterns is already under investigation in cut and sew clothing. (Daanen and Hong, 2008: 15-25) [TC]2's '3D to 2D' pattern making software can transfer data into CAD patterns; 'Scans for Sewing' have taken this ability and offer individual home sewing 'slopers' from body scan measurements. Using client's scans, Customised swimwear is available in America and Lane Bryant scanned 14,000 customers to inform new jeans sizing. ([TC]^2, 2007; King, 2008; McLaughlin, 2008). In 2006, Dr Bruner of [TC]^2 (US Textile Clothing Technology Corporation who produce the NX scanners) was hopeful that they might demonstrate custom garment output from integrating scan data with a Shima Seiki knitting machine; at the time of writing the integration has not been effected (Bruner, 2006).

In 1995, Shima Seiki opened their Factory Boutique in Wakayama, Japan, where customers design a knitted garment to their liking in about two hours at a price comparable to quality garments in the high street (15,000–30,000 yen or £95–£188 at time of writing). Although the actual knitting takes 30 minutes, delivery can take up to a week (fibre2fashion, 2006; Shima Seiki Mfg., 2008). Shima's boutique uses the Wholegarment® machine's ability to knit seamless garments requiring little finishing but highly experienced programmers. My premise is that the SES flat v-bed machine is neither as expensive nor as complex to programme, yet can deliver 3D shape, although garments require finishing.

Body shape

Whilst it may not, feel 'safe' to articulate in public 'this is too small' or 'I am too big', online there is an active and vocal community of women expressing themselves about clothing size, body shape and problems they encounter with fit and availability. Tapping into this phenomenon through the online survey has provided anecdotal evidence on which to draw. This survey was targeted through web groups focusing on large women's apparel, such as Ample Knitters, and flyers packed with online purchases of large-sized garments and knitting yarn. The heartfelt comment 'just because I'm fat doesn't mean I have arms like a gorilla!' exemplifies one of the commonest problems; the incidence of relationally disproportionate body dimensions amongst larger women. Ashdown observed: 'Within each size category, it is assumed that the taller women are, the wider they are', and yet bar some exceptions, grading-up sizes without reassessing proportions continues (Land, 1995, p. 3).

More recently Ashdown has led research into body shape and apparel, but no one has been found to be working specifically with knitwear, a 'flexible' fabric, where inherent elasticity of the loop structure can accommodate bodily differences. This extensibility, caused by robbing back between stitches produces a fabric that is 'highly probable to recover its original size' (Smirfitt, 1975, p. 8–9).

A size 22 respondent commented: 'Availability of clothes for larger people seems out of step with the % of the population who are large.' Similarly, a 60-year-old, size 16 woman wrote: 'Clothing for my size (and age) is either extremely expensive or nonexistent.' 38% of respondents commented with varying degrees of dissatisfaction on clothing fit and availability. One observed: 'Every "plus size" model I have ever seen in shops or catalogues is more of an oversize hourglass figure. Larger – but still with a defined waist and small tummy', clearly demonstrating the depth of analysis applied by women to their body shape and retail experiences.

Not only has the waist proved to be a contentious area, but also survey data demonstrates that women do not conform to standard sizes. Of the Apple-shaped women who described themselves as having 'wide shoulders/upper body', 67% reported proportionally sized bust to hips. Meanwhile of women who described themselves as either 'wide-waisted with a round tummy' (Ovoid) or 'generously proportioned with undefined waist' (Large Ovoid), only 36% of each group reported themselves as being the same size at bust as at hip.

Table of Apple shape body sizes
Shows percentages of equal size lower to upper body size and different sized lower to upper body size.

	Lower body size					Apple total
upper body size	14	16	18	20	22	
upper body size 14	0.00%	11.11%	0.00%	0.00%	0.00%	11.11%
upper body size 16	0.00%	22.22%	0.00%	0.00%	0.00%	22.22%
upper body size 18	11.11%	0.00%	11.11%	0.00%	0.00%	22.22%
upper body size 20	0.00%	0.00%	11.11%	11.11%	0.00%	22.22%
upper body size 22	0.00%	0.00%	0.00%	0.00%	22.22%	22.22%
Grand total	11.11%	33.33%	22.22%	11.11%	22.22%	100.00%

Table of Ovoid shape body sizes
Shows percentages of equal size lower to upper body size and different sized lower to upper body size.

	Lower body size					Ovoid total
upper body size	14	16	18	20	22	
upper body size 14	2.17%	0.00%	0.00%	0.00%	0.00%	2.17%
upper body size 16	4.35%	4.35%	4.35%	2.17%	2.17%	17.39%
upper body size 18	0.00%	8.70%	6.52%	13.04%	0.00%	28.26%
upper body size 20	0.00%	2.17%	4.35%	6.52%	10.87%	23.91%
upper body size 22	0.00%	0.00%	2.17%	6.52%	19.57%	28.26%
Grand total	6.52%	15.22%	17.39%	28.26%	32.61%	100.00%

Table of Large Ovoid shape body sizes

Shows percentages of equal size lower to upper body size and different sized lower to upper body size.

	Lower body size				Large Ovoid total
upper body size	16	18	20	22	
upper body size 16	18.18%	9.09%	18.18%	0.00%	45.45%
upper body size 20	0.00%	0.00%	18.18%	9.09%	27.27%
upper body size 22	0.00%	0.00%	27.27%	0.00%	27.27%
Grand total	18.18%	9.09%	63.64%	9.09%	100.00%

Figure 2: Tables of data taken from the online survey, showing percentages of equal and different lower to upper body size by body shape

In 2000, the US plus-size market was worth $32 billion (20% of the total market) and increasing, and UK consumers spend over £23 billion a year on clothing (Gardyn, 2003, p. 2). It would seem sensible to target design, manufacture and retail at this lucrative, growing and increasingly discerning market.

Body cathexis

It has been found that weight loss encourages women to wear brighter and more fitted clothing, thereby indicating increased satisfaction with parts of their bodies (body cathexis) (Robinson, 2003, p. 187). It is also thought that elevated body cathexis has a positive effect on satisfaction with the self; LaBat and Delong found that the fit of clothing correlated to the level of body cathexis. In which case could it not be possible that if clothing fits well, without stretching or straining over the body shape, or cinching in on soft areas, it may encourage positive body cathexis?

Love your clothing

Chapman, in *Emotionally Durable Design*, discusses whether consumer/product relationships may contribute to sustainable production (Chapman, 2005, p. 224). It is possible that garments in which the consumer invests personal design choices may equally contribute. Improved satisfaction with fit, style and potential elevated body cathexis, as described by LaBat and DeLong, may encourage longevity. In conversation with one participant who had lost weight during the research, she admitted to keeping smaller clothes from her youth because she liked the way she looked in them. She added, 'You know, with a bit of help, you could really look brilliant in the bigger sizes, but it's the clothes you get to fit those sizes that are useless.' She observed that on her salary (middle management), she could not afford garments she considered well cut, settling instead for those she knew would not be satisfactory, which she would not wear for long.

There are sustainability and ethical issues with cotton and other cellulose fibres due to fertilisers, pesticides and excessive water usage (Swift, 2007, pp. 7–13). Although wool is not necessarily sustainable, comfort is one of the goals of the research. Therefore, as the physiology of larger-sized women is more suited to natural or wicking fibres, wool was the informed choice for the research yarn (Deckert, 1999, p. 154).

Methods

A unique methodology has emerged from various disciplines, including designing a measurement system specific to large-sized women, visual evaluation, measurement analysis, deductive approaches to data, simple statistical analysis, semi- structured interviewing, multiple choice questionnaires, and participatory feedback. Focused oral histories were taken whilst discussing clothing preferences and retail experiences.

A pilot study culminated in a longitudinal collection of samples and prototype garments whilst contributing to the design and inception of a main study, for which two women over size 16 were recruited. Recruitment was predetermined by certain factors: body size, geographical location, time commitments, level of confidence and machinery capability. The latter was influenced by the type of knitting machine available for sampling, but results remain transferable. Problems encountered included requiring assistance to carry out manual measuring, and the need for visual as well as written feedback forms; both issues being tested and resolved through the pilot study. The main study is now complete apart from the final evaluation of the third garment (at time of writing).

Designing a body measuring system specific to larger sizes
Initially Heath Carter's somatotypes were considered, however simpler categories specific to plumper women were preferred, for which American 'plus size' pattern developers Cooklin, Deckert and Betzina were consulted. Front silhouette, sagittal plane posture (side view) and fat deposition were categorised. Referring to a variety of authorites, including Pheasant's work on ergonomics and anthropometry, a unique system of relational body landmarks was established (Pheasant, 2001). Measuring between these predetermined landmarks, dimensions and relational body proportions were ascertained. Measuring was initially by traditional methods, enabling construction of life-sized 'clones' of the participant's torso, which facilitated continual evaluation.

Certain girths are not traditional; for example the 'waist' is not the preferred waistband position, but where the mid torso is narrowest, whilst a critical marker is the most protruding point of the stomach. To use this information to inform the fit of the front panel of a garment, it is necessary to know its vertical position between bust and widest lower frontal width (hip), distance horizontally in space relative to these parts of the body (X-Y position) and the girth's distribution around the body.

Figure 3: Building clone 2. From left: capturing actual body shape, mounting on stand, completed clone

These latter two are the most difficult to establish by manual methods. An anthropometric calliper aligned with fixed vertical markers was used to measure specific body depths, and in combination with horizontal markers in space, this ascertained girth distribution; these were supplemented by visual assessment.

Measuring sessions created opportunities for informal interviews and familiarisation with each participant's body shape; data collected during these, plus 'clones', photographs and video footage of the measuring sessions supported knit prototyping.

The second participant was 3D body scanned. $[TC]^2$'s NX12 software for extracting measurements only offers basic landmarks, therefore the predetermined landmarks were programmed into the software to generate measurements uniquely suited to larger-sized women's body shape. This data augmented manual measuring information, whilst the clone was used for fabric testing. This participant's dramatic weight loss during the research period rendered subsequent trying-on evaluations unreliable, however body scan data and her clone meant that the project could continue. As a by-product of this, interviews with this participant have yielded valuable information about body shape change, its effect on psychological well-being, self-esteem and clothing choices.

The third participant was only body scanned. No clone was made; only scan data, in conjunction with manual measurements of areas inefficiently covered by the scanner (for example the underarm area), was translated into knitted garments. In order to do this 'blind', further additions were made to the landmarks in the scanner software. To date, this garment has not been evaluated on the participant due to a break in study.

This transition into electronic body scanning has opened up discussion around the possibilities of direct data transfer; exploring the link between body scanning and custom-made knitwear in a small area of the market.

Designing a contextual topographic and evaluation system

Knitting is extensible, therefore it is necessary to be able to measure its behaviour on a 3D surface. Watkins writes about applying surface grids to test stretch; by adopting this precedent, a 2-cm grid was designed and permanently configured onto each garment to monitor extension and relaxation (Watkins, 1995, p. 241). Because the grid is embedded into the interlinked stitches, routes to the source of distortion can be mapped, creating an accurate and rigorous stretch-evaluation tool.

Prototyping

Fabric consistency was controlled with shrink-resistant yarn and common stitch densities, producing a supple fabric, less complex to programme and analyse than multi-colour techniques. Reverse loops form permanent surface-pattern-to-stitch ratios, highlighting extension, ecru yarn maintains stitch clarity and Bilorex® elastane stabilises the grid, reducing misreading (Spencer, 2001, p. 379; Smirfitt, 1975). Narrowing, widening, progressive wale transfer and flèchage give 3D shape to the garments.

The first area addressed was the bust. As a prominent area usually accommodated by extension of the knitted stitches, it presented an important starting point. Experience in knitting predicted that flèchage (knitting short rows), would provide complimentary, 3D shaping at the bust. The technique has a similar effect to darting in pattern cutting; however, as the darts are knitted integrally there are no seams. The stitches from each converging plane run smoothly into each other without distorting the garment surface.

The number of courses and wales over which flèchage occurs are directly influenced by calculations involving the differences between the participant's front bust width, distance between bust points, centre front length over the bust to a fixed point from the floor, and centre back body length to the same point at the back.

centre front-centre back = depth of flèchage

$$\frac{(\text{front bust width} - \text{bust points distance}) + 4\text{ cm}}{2} = \text{width of flèchage in cm}$$

This calculation enabled the first 3D samples. Side seam positioning of the flèchage was initially based on the bust points, but due to the way courses are slightly compressed by flèchage, this produced a raised dart, placing the 3D shape in the wrong position. Progressive samples were knitted, and after further analysis of results the darts were positioned 2 cm lower to compensate for this effect. Further investigations into flèchage, based on Lewis's mitre examples, have led to the 'spiral A' development, which lays the dart at a slight upwards incline towards the bust point (Lewis & Weissman, 1986, p. 266). Participant feedback signalled this as complimentary to larger and/or lower bust lines.

Vertical darting transfers groups of stitches so that the fabric narrows or widens internally rather than on the edge; therefore more volume can be added at points throughout the body surface. With participant one this was necessary on the stomach and on the upper back, whereas on participant two this was also necessary on the upper hip. In participant three, who has a frontal hourglass shape, but a pronounced abdominal protrusion, darting creates flare on the lower front body panel. Positioning and incidence of darting was informed by 'body slices' that scanning makes possible.

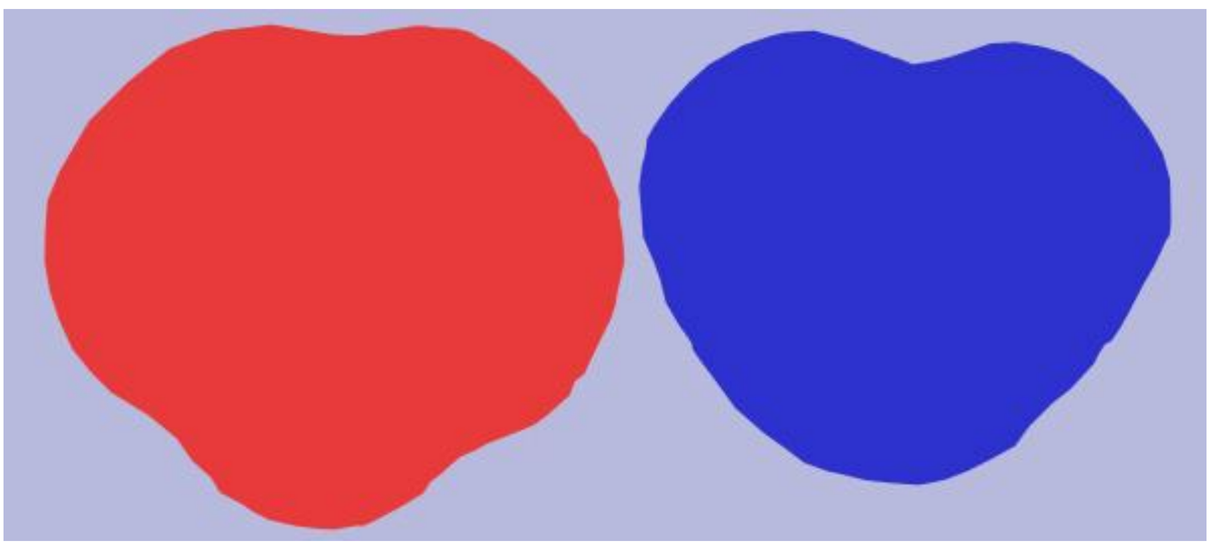

Figure 4: Body slices from participant two at high hip (left) and narrowest girth of torso (right), illustrating the markedly different deposition of body tissue that the garment has to accommodate in a relationally short distance

Because scanning indicated that participant three had distinctly uneven shoulders in length and slope, the garment has been knitted with this as a consideration. Combinations of asymmetrical dimensions and internal darting have captured this and it is anticipated that the garment will drape without distortion at the hem or shoulder.

Asymmetrical shoulders caused the sleeve head shaping for each sleeve to be different. These disparities were addressed by inputting scanned measurements into the Shima

Seiki pattern drafting software (PGM); manual adjustments were necessary at this stage as the interface does not offer asymmetrical input. These 2D patterns were translated into knitting schema (Knitpaint), where 3D elements were cut and pasted from earlier templates. Further customisation was based on body slices, visual evaluation of body shape and information offered by the participant about her fit preferences, e.g. length of garment, length of sleeve. Additional manual programming was required to accommodate her shoulder imbalance.

Evaluation

I have observed that participants need to look in a mirror, pull the fabric and touch their body in order to satisfy their curiosity about fit. To achieve useable, valid results the participants have been questioned in a semi-structured way, focusing on fit and feel rather than aesthetics. This subjective, inside-out view of fit and comfort is augmented by both concurrent objective evaluation and subsequent examination of images of worn garments, employing collision (body with fabric) and wrinkle detection and analysis and observing grid distortion.

In flat pattern fitting, wrinkle analysis is a long-established practice (Watkins, 1995, p. 242). Folds caused by protrusions are constrained by darts and pleats, creating a 3D shape to accommodate the protuberance; however this excess fabric bulk remains, and if cut off creates an internal seam that may cause discomfort. Following similar principles, but integrating darts within the structure, a smooth 3D shape can be knitted. Equally, where girth varies longitudinally, for example from full buttocks to a narrow upper back, an inverse vertical dart can be integrated.

Evaluation includes neck shape; participant two has an upper cervical spine protrusion, preferring a low back neckline; this was incorporated into subsequent garments.

Findings so far

Manual and body scan data, revisions and re-evaluations have been interpreted into a series of 3D knitted shapes; respecting yet questioning rules and accepted practices of knitting, knitwear and clothing construction. During the practical phase of the research, a library of templates has been accrued for future developments.

Wearer analysis so far shows that women value the prototype garment's comfortable fit, which eliminates stitch distortion whilst reducing the drooping, folding and cling commonly found in larger women's knit clothing (Myers McDevitt, 2004, p. 246). The knitted garments visibly demonstrate refined relationships to an individual body shape. As hypothesised, flèchage and internal narrowing/widening directly influence the space between body and knitting by referring wales and courses around the body, moving 'ease' from areas of excess width or length caused by the body shape beneath to those where it is lacking, thereby reducing body to garment collision and eliminating wrinkles, and hem dip. For example, at bust level on the side seam, less fabric length is needed than that required to contour the bust protrusion. By removing length commensurate with this discrepancy, the side seam remains the same length as the front of the garment when worn, preventing the hem dipping at the side and possible excess wrinkles at the underarm. In participant two it was necessary to employ additional flèchage directly above the hem because she had a high protruding stomach requiring more length at centre front, but a small bra cup size which did not allow sufficient length to be removed at the bust.

The comfort of the participant has been questioned at each stage and converging positive responses such as 'I don't feel like I'm wearing anything' and 'Can you make one for me to wear next?' suggest a high level of wearer satisfaction. These findings will be augmented and verified by the evaluation of the third garment and further analysis of all evaluation session data.

Future plans

Once the research is completed, the template library will have international value, based in common knitting principles and a universal colour-coded language. It may contribute to the development of a successful dialogue, bridging the gap between the 'cognitive styles of designer and technician'; traditional professional boundaries problematic in knitting (Eckert, 1999, pp. 29–42; European Monitoring Centre on Change, 2005–06, p. 13).

Postdoctoral collaboration with retail and manufacturing is anticipated to produce commercial samples, and in the absence of many contemporary texts on industrial knitting, this work could possibly form a basis for publication.

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