10
Garment design for individual fit

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10.1 Introduction

Pattern making is the process of transforming three-dimensional designs into their two-dimensional constituent pattern pieces. Traditionally, pattern making in the apparel industry involves the process of obtaining the linear measurements over the body surface with a tape measure, and then applying these measurements to draft the pattern based on a mathematical foundation and approximation. The body form comprises both convex and concave surfaces, and no two bodies are identical. As noted by Whife,[1] however many measurements are taken from a human body and however carefully they may be applied to a pattern, this will not guarantee a perfectly fitted garment since measurements alone cannot fully determine the shape of the human body. An 'observation' and 'judgment' of shapes and contours must be applied in order to achieve a good fit.

According to Bray,[2] defects in garments are connected with, and conditioned by, a variety of circumstances; the shape of the figure is one of the concerns apart from the texture of the fabric, and type of garment and the way it is worn.

Anglais[3] also stated that most of the fitting problems are due to figure abnormalities. Therefore, the activities of garment cutting and fitting include correct measurements and figure observations – careful cutting and accurate fitting.[4]

Body contour, posture, body proportion and symmetry affect the fit of clothing. Patterns are designed for an average symmetrical body shape, with standard posture and body proportions. Very few individuals are the same size and shape as this standard model; therefore, pattern alterations need to be made before garment pieces are cut and fitting adjustments are also made during the assembly process.[5]

10.2 Pattern alteration for fit

Barnes[6] stated that making clothing which really fits is one of garment making's greatest challenges – and crucial successes. No matter how lovely the fabric, how fine the garment design, or how expert the sewing, the results are disappointing if the garment fits poorly. Bray[7] pointed out the difficulty of applying contour measurements to a flat surface and stated that results are bound to be somewhat approximate, and inaccuracies have to be allowed for.

There are numerous texts containing studies of the body form and illustrated methods of pattern alteration for different figure types to achieve fit, especially based on the problems relating to different figure types.

10.2.1 Study of the human anatomy

Analysis of ladies' figures

Whife[1] investigated three female figures and found that although the circumferential measurements of bust, waist and hips of the three figures might appear similar, the shapes of these figures were quite different and would require different shaped garments to give an accurate fit. Whife[1] also found that although all three figures had exactly the same chest girth and might have the same bust girth, the bust shape clearly differed from one figure to another and the distances between the bust line and chest line were also different. The figures had different bust lengths from the shoulder, and the distances between the breast and waistline also differed considerably. It was clearly evident from the figures that chest and bust girths are not in themselves indicators of chest and bust shape.

Perry[8] noted that improper posture might cause clothing fitting problems. The rigid or extremely erect figure shortens the distance from the back of the neck to the shoulder blade, and lengthens the distance from the base of the neck to the apex of the bust thereby causing fitting problems. The opposite of this rigid posture is a slumped figure, which will cause fitting problems due to rounded shoulders, dowager's hump, sway back and protruding abdomen.

Rasband[9] classified ladies' body shapes into eight types: ideal, triangular, inverted triangular, rectangular, hourglass, diamond-shaped, tubular and rounded.

Researchers found that as the body ages, certain predictable physical changes take place. Goldsberry and Reich[10] noted that the more obvious changes are the expansion of the waist and abdominal girth, coupled with a shortening of the spinal column. Katou and Nakaho[11] found that the lower half of the body of elderly women, especially the abdomen and hips, undergo noticeable changes as they grow older. Similarly, Le Pechoux and Ghosh[12] found that elderly women will tend to become larger around the waist, hips and thighs, with spinal column curving and shortening. From the age of 50 onwards, the body fat of women decreases at a rate of 1% annually, also indicating that their overall body dimensions are becoming smaller. Studies conducted by NTC (National Textile Center) Project No. I01–A27 indicate that body dimensions vary according to posture and shape, especially as people become older.[13]

Larson[14] found that the fit of trousers is affected not only by how accurately the pattern pieces reflect the wearer's measurements and contours but also by her posture. It is entirely possible for the pattern pieces for two people having the same hip and waist measurements to be quite different.

Analysis of men's figures
In a text for men's tailoring, Whife[15] classified men's figures into nine different figure types, namely: 1 Stooping, 2 Short neck, square, 3 Normal, 4 Long neck, sloping, 5 Head forward, 6 Erect, 7 Corpulent, 8 Tall and thin, and 9 Large shoulders. A similar approach was adopted by Waisman.[16] The authors of both textbooks stressed that figure abnormalities cause fitting problems.

To analyse men's figures, Frederic[17] suggested that the customer first be viewed from the front to ascertain whether he is sloping or square shouldered, and to ascertain the development of his muscles to check whether the figure is broad or narrow chested. Thereafter the customer is viewed from the side to determine and stipulate to what degree he stoops, or is erect, or to what degree the head leans forward or backwards. Then, he needs to be viewed from the back to determine and stipulate to what degree the customer has large or small shoulder blades or a long or short neck. Frederic found that there might be a combination of two or more figure types in one subject. For example, a man can be both sloping and stooping. He can also be sloping, stooping and have large shoulder blades, and then also have a long or short neck; or he can be square, with small shoulder blades and erect, etc.

Another study[18] categorises men's figures into four main body types, A, B, C and D. Body type A is a figure of average build with a normal drop and rise. Body type B is a figure of slender build, with narrow and sloping shoulders, and a flat chest. This figure has an average drop, but generally a short rise. Body type C represents a figure with narrow and sloping shoulders, shallow chest and a full waistline. This figure generally requires suits with a small drop and high-rise trousers. Body type D represents a figure with broad and square shoulders, deep chest and heavy shoulder blades. This figure usually has a flat stomach and small waist, requiring a high drop suit and high-rise trousers. As noted by Boswell,[19] 'drop' is defined as the difference between the chest and the waist and the 'rise' refers to the distance from the waist to the top of the inseam.

10.2.2 Methods of pattern alteration

Traditionally, alteration of garment patterns is an essential step in producing attractive and accurately fitting clothing from patterns which already exist. There have been numerous publications by tailoring experts on how to alter garment patterns for different figure forms. Texts of pattern alterations for ladies include those by Perry[8]; Bray[2,7]; Liechty *et al.*[20]; Brackelsberg and Marshall[5]; Aldrich[21]; Rasband[9]; Barnes[6]; Betzina[22] and others. Tests for pattern alterations for men's tailoring include Marcus[23]; Wilson[4]; Doblin and Frank[24]; Anglais[3]; Whife[15]; Frederic[17]; Anon[18]; Aldrich[25] and Brinkley.[26] Brumbaugh and Mowat[27] provided step-by-step self-instructional guidelines for altering women's and men's tailoring patterns.

Alterations can be done by using measurements, taken by a tape measure and incorporating them onto a paper pattern using the slash, seam or pivot methods.[20] In the instructions provided by Liechty *et al.*,[20] fitting by measurement is accomplished by comparing the body measurements, with an ease allowance added to the measurements on the pattern. Measurements may also be obtained by measuring a basic garment or personalised basic pattern. The body measurements, with the ease allowance added, are then compared to the corresponding locations on the pattern piece, adjusting the pattern where body measurements agree or where they extend beyond the pattern edge.

Taylor[28] reported that most of the problems concerning the fit of the rest of the garment, that is the bust, waist and hip measurements, can be resolved simply by increasing or decreasing the size of the garment part proportionally according to the style details.

10.2.3 Pattern alteration for flattering the figure

The fitting itself should be conducted in such a way that it will achieve a good and accurate fit, pleasing style lines and satisfy the customer.[4] One of the greatest functions of clothing is to hide figure problems and to make the most of good features, also creating optical illusions and camouflage.[27] The ultimate goal is to design clothing that fits and looks beautiful on the person, by adding ease to garments worn by larger women and to camouflage the body shape.[29]

Some tailors consider shoulders to be the key to a well-fitted jacket. Hutchinson and Munden[30] maintained that the critical area of the body concerning fit was around the shoulders. They stated that if garments fit the figure perfectly between the neck and the horizontal line encircling the figure at the lowest level of the armhole, then the main fitting difficulties would be overcome. Roeher[31] supported this view, maintaining that jackets are not close-fitting garments at the bust and sleeves, and that many figures can be fitted to perfection with only shoulder corrections plus minor length and circumference adjustments at the hem and side seams. There are also no definite rules for the shoulder width. Shoulders on some oversized jacket patterns extend as much as three inches on either side past the normal shoulder measurement. Roehr[31] further advised that shoulder pads could not adequately support a jacket for more than 1½ inches beyond the normal shoulder level without making creases, as many shoulder lines are exaggerated.

In the fitting of trousers, Larson[14] specified that a proper fit is the result of recognising an individual's prominent contours and draping the trousers so that they skim the body's profile. Regardless of the figure, good fit involves a combination of three basic issues: the garment function, its style and its structure. Trousers should move comfortably with the body when sitting, standing, bending, walking or climbing. There should be no restriction of movement or uncomfortable binding. The style of the trousers should be proportional to the body. Slim cigarette trousers look much better on a slim figure than on a heavy one. Beautifully fitted trousers skim the body, hiding its flaws and accentuating the good points.

10.2.4 Pattern alteration for non-standard figures

Clothing companies usually design with standard figures in mind, based on the company's background and the statistical average of many figures. Such standards are considered as 'ideal' in terms of proportions, contours, symmetry and posture. However, due to heredity, ethnic origin, growth patterns, disease or accident, the figure of the individual may vary from the standard.[20]

For asymmetrical variations, Liechty *et al.*[20] noted that when the left side of the body differs significantly from the right side, the fitting pattern must be duplicated to have a pattern for each side of the body. Each side is then altered where necessary. This results in different pattern outlines for each side of the body for the bodice, skirt, or sleeve units. This approach is also supported by Komives *et al.*[32]

For a wearer with a curved spine and asymmetrical body, Komives *et al.*[32] suggested making a four-part pattern, especially for the bodice, which fits separately to the left and right fronts and backs, and then joining the pattern pieces at centre front and centre back, making the back closure (if any) perpendicular to the ground rather than following the spine. She pointed out that a tightly-fitting garment on an imbalanced body could often draw attention to the irregularities. Garments which hang from the shoulder are the most flattering and require minimal fitting, while separates tend to accentuate physical misalignments.

Tam Wong[33] suggested that garment design and cutting must not only enhance the appearance of disabled people, but also cope with individual disabilities. Women suffering from Down's syndrome encounter clothing problems due to their non-standard figures. Proper design and cutting may help to improve the wearer's ability to care for themselves. Similarly, authors have suggested the necessary adjustments for trousers to be worn by persons with artificial limbs[15] and Komives *et al.*[32] tried altering trousers, so that they can be worn comfortably by people who have to sit in wheelchairs and need to wear the trousers over diapers, by lengthening the back crotch and widening the seat of the trousers using the slash method.

The Fashion Institute of Technology (FIT) and the National Osteoporosis Foundation (NOF) established a competition, called 'Beauty in All Forms', which aimed to design a line of clothing for women whose body shapes have changed because of osteoporosis. The specific feature of clothing for people with osteoporosis was that the back length of the jacket might be a little bit longer than the front, giving it a slightly different style line and shaping.[34]

10.2.5 Pattern alteration with experimental methods

To reduce trial and error in fitting and measuring, and to expand the use of the computer as a tool for quantification and plotting, many researchers have contributed to the evolving scientific methodology of pattern alteration as an alternative to the hand-drafted empirical approach.

Douty[35, 36] applied 'graphic somatometry', in which silhouettes of female subjects were projected through a grid screen. These somatographs were analysed for posture, general body mass, proportion, contour, balance and symmetry of body. This method helps to identify body variations in forms and shapes. Later, Douty and Ziegler[37] used 'graphic somatometry' to identify configurations of problem figures and to quantify the alterations needed for adjusting patterns. They developed an experimental method which they compared with the traditional method for pattern alterations. The experimental method included detailed measurements to establish dimensions, and somatographs to show proportions of body segments, for contour analysis and angle measurements. It was concluded that the experimental method achieved better results for most figures.

Farrell-Beck and Pouliot[38] found that it was not easy to alter trousers to fit the contours of hips and thighs as neither the shape nor the contour can be determined from traditional methods of measurement. They then compared two sets of trousers altered by traditional and experimental methods, respectively, in order to develop a method for alteration of trousers that incorporates body measurements, graphing techniques and the body angle. Data points from somatographs were used to plot full-scale body contours for 36 female subjects. The quadratic interpolation and cubic spline interpolation were developed to correct and plot full-scale representations of the body curves. One muslin garment was cut from a pattern altered by the experimental method and the second muslin garment from a pattern altered by the traditional method. Results showed that the experimental method was preferred over the traditional method for front waist placement, front waist dart size, back crotch curve and horizontal grain. For all other criteria, the fit produced by the two methods was rated as equal. Farrell-Beck and Pouliot[38] concluded that no one method of alteration solves all problems efficiently. Some pattern corrections can be made quite satisfactorily by traditional methods, especially changes in length and circumference. The experimental method offers a means of calculating the amount and location of changes when figure variations demand adjustment of angles.

Brackelsberg *et al.*[39] developed an experimental method of pattern alteration for a set with the bodice attached to the skirt. Information on body angle was added in addition to the length and circumference measurements used by conventional alteration methods. These angle measurements were obtained from computer-drawn plots of the body profile and were used to alter the dart size and length and slope of the shoulder seam. This experimental method was then compared to the conventional method of alteration. The results indicated that models with deep body angles were more satisfactorily fitted when using the traditional methods, whereas models with shallow body angles benefited more from the use of the experimental methods.

Brackelsberg *et al.*'s results[39] were further clarified by Winakor *et al.*[40] who pointed out that the bust has a rounded or domed shape rather than the pointed shape of the geometric models. The bust angle was measured by placing the straight edge on the surface of the breast which makes the apex of the angle lie beyond the bust point. A space was formed between the bust point and the apex of the angle which therefore caused excess fullness in the bust region.

Heisey *et al.*[41] developed a method of pattern alteration using mathematical analysis of the graphic somatometry. The angle of a dart or a seam was determined from angles measured on the silhouette somatographs of the body. An exact geometric relationship between the angle measured on the photograph and the angle of the dart or seam on the pattern was derived for those areas of the garments that can be modelled with cones. Although Heisey *et al.*'s approach of modelling the body as a series of conical shapes seems valid in theory, it is not entirely satisfactory for any area in which the garment must curve in more than one direction, e.g. the side seams of the skirt and trousers and possibly the shoulder area of the bodice.

The somatometry approach has been used to describe the graphical human body shape by researchers in the development of a methodology for pattern alterations. Though success with this methodology has been limited, the approach offers the potential for providing more accurate measurements than the traditional method of body measurement.[42]

10.2.6 Pattern alteration using computer-aided design (CAD) programs

Experienced pattern markers have developed a set of heuristics that enable them to make pattern changes rapidly. Nevertheless, computer systems do not have the 'experience' or background knowledge which experienced pattern markers have to accomplish rapid alterations. Although CAD systems cannot learn by experience, once the heuristics have been developed within a CAD system, it can process the information and perform the functions more rapidly, accurately and consistently than the most experienced pattern marker.[43]

Most apparel CAD systems (Gerber Technologies, Lectra Systems, Investronica, Assyst, PAD and Optitex) have several preparatory activities in common which will allow automatic pattern alterations based on individual measurements. Although each system has a different interface to the others, the basic underlying theory is the same. These preparatory activities are laborious in the beginning, but ultimately allow the automatic alteration of existing garment patterns.[43]

The mass production strategies of the past decades have categorised whole populations by a relatively small number of sizing systems which have made it virtually impossible to meet the needs of those individuals who have special fitting requirements. Developments in information technology have increased the probability of mass customisation (defined as the mass production of customised goods by Davis[44]) being adopted as an acceptable business strategy. CAD alteration systems will enable the creation of garments, customised for fit, very quickly and accurately. These customised garments can be inserted into normal production lines as an additional 'size' and produced like every other garment of the same style.[43]

10.3 Prediction of garment patterns from body measurements

Clothing design and pattern development sources have referenced various body types with corresponding pattern alteration techniques. Pattern alteration would, of course, greatly depend on one's experience and ability clearly to visualise the shape of the figure.[2] This approach is essentially an intuitive visual analysis of the body with major assumptions made about their relationship to the pattern shape.[45]

10.3.1 Pattern generation using photographic and anthropometric data

Similar to Heisey *et al.*'s approach[41] for pattern alteration using a series of right circular cones and graphic somatometry, Winakor *et al.*[40] developed and tested a pattern for the lower part of the female bodice by using quasi-conical surfaces which have a hyper-elliptical cross-section which represents a horizontal cross-section through the body as shown in Fig. 10.1. The cones that modelled the body form can be unrolled to form flat surfaces without loss of information. Figure 10.2 shows the computer draft experimental pattern.

Data for analysis came from measurements of rigid body forms and somatographs of these forms. A computer was used to calculate and plot the patterns. The experimental patterns were compared to the patterns draped on the body forms. It was found that although a reasonably good fit was obtained for some forms, the quality of fit was limited by difficulties in obtaining consistent data from the measurements and somatographs. It was found that the cone-shaped draft could be extended to the back bodice and the skirt. Winakor *et al.*[40] concluded that this research demonstrated that a simple geometric model, when

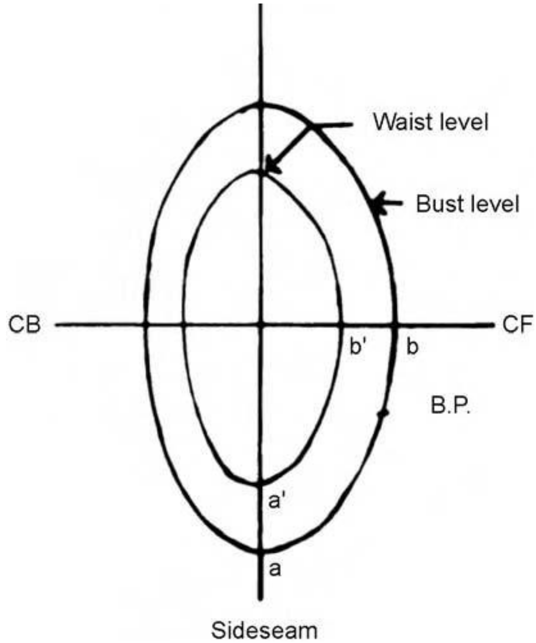


Figure 10.1 Cross-sectional view of the geometric model for the experimental pattern. Source: Winakor *et al.*, 1990.[40]

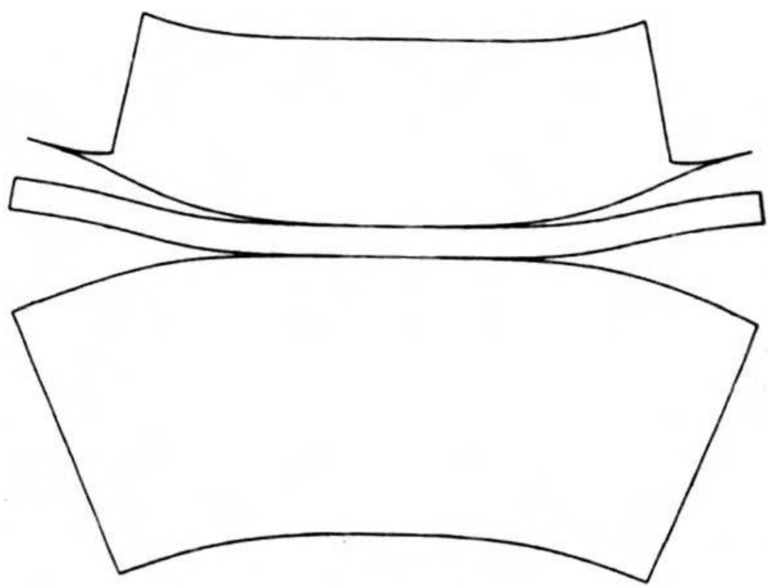


Figure 10.2 Computer pattern draft of experimental pattern. Source: Winakor *et al.*, 1990.[40]

based on geometrically consistent measurements, provides a reasonable estimate of the lower bodice dart opening and dart angle.

The imprecise nature of taking linear body measurements with a tape measure and then applying such measurements for pattern drafting is evidenced by the need for repeated trials and fittings of the garment by a skilled technician after the pattern has been cut from cloth. Experience has shown that these linear body measurements are not directly applicable to pattern dimensions and are useful primarily as approximations. Gazzuolo *et al.*[45] therefore carried out research to develop garment patterns from photographic and anthropometrical measurements of the body. They developed statistical regression models to predict the dimensions of a planar pattern (i.e. a close-fitting experimental garment pattern for the bodice of the female body form) from both traditional linear and photographic body measurements. In their study, photographic data were compared with linear anthropometric data as predictors of pattern dimensions. The statistical regression models developed indicated that, while linear measurements were slightly more accurate in predicting a few of the pattern dimensions, the photographic measurements were more accurate in predicting others, particularly pattern angles. Gazzuolo *et al.*[45] concluded that photographic measurements held promise as an alternative to the more intrusive linear measurements for predicting pattern dimensions. Schematic diagrams showing the locations of photographic measurements are given in Fig. 10.3.

The approach of Douty,[36] involving the somatograph technique to help identify body variations in forms and shapes, was also adopted by Shen and Huck[42] to determine body angles and curves. They utilised the captured two-dimensional photographic image in conjunction with the models to estimate body measurements and shapes.

In the research of Shen and Huck,[42] the geometric nature of 12 female bodices with various configurations was obtained using photographic data and physical measurements. A computer program was written to generate block patterns for the female bodices using the data. A conventional pattern drafting

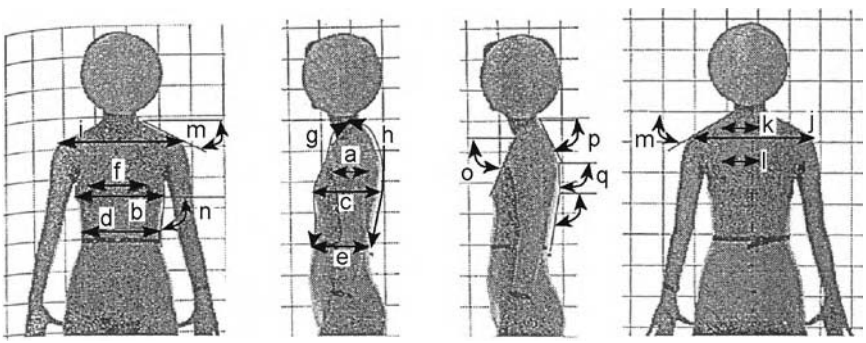


Figure 10.3 Locations of photographic measurements. Source: Gazzuolo *et al.*, 1992.[45]

method was used to develop hand-drafted bodice patterns. An evaluation scale, which included 25 fitting criteria, was developed to compare the fit of the experimental bodices with that of the hand-drafted bodices. For 12 of the 25 items on the scale, the experimental bodices were judged to have a better fit than those produced by the hand-drafted method. For two items on the scale, the hand-drafted bodices provided a better fit. No statistically significant differences were found for the remaining 11 items on the fit scale. This methodology showed potential for providing accurate, quickly generated bodice patterns.

Research has been carried by Chan *et al.*[46] to predict shirt patterns from 3D body measurements. The pattern parameters of men's shirts were correlated with the body measurements of the model generated from a Tecmath laser body scanner. A high correlation was found between the parameters of the two-dimensional shirt patterns and the three-dimensional body measurements. It was revealed that prediction equations could be established, using multiple linear regressions, to predict important pattern parameters. The authors concluded that the prediction equations could be improved by using Artificial Neural Network.

10.3.2 Pattern generation from 'made-to-measure' systems

A research team at the University of Maryland has developed an open-ended Clothing Design Expert System (CDES) which can process the codified expertise of garment design and alterations and generate patterns for made-to-measure garments. Two tools were developed in this system: The Alteration Definition Tool (ADT) is a CAD-like environment in which the user generates and stores sets of alteration sequences which will modify a pattern geometrically. The Pattern Requirement Language (PRL) executes the alteration sequences generated with the ADT and converts the data contained in a customer's order to enable a custom-made garment to be produced. The system can also create new base patterns by altering existing patterns. Through the development of CDES, the alteration of made-to-measure garments has shifted from a manual procedure to a computerised set of procedures.[47]

Made-to-measure software is available from Gerber, Lectra and other commercial CAD/CAM garment systems; these are, however, more costly and more complex to operate. In view of this, Turner[48] developed a PC-based CAD system, called MICROFIT, for producing made-to-measure garment patterns in the commercial environment of a bridal wear manufacturer. The main structure of the system contained functions which could generate made-to-measure patterns through digitising and grading and then plotting the resultant pattern pieces. The fundamental elements of the made-to-measure system were based principally on making structured inquiries from customers to find out their body measurements, specific body form and dictated style specifications. The computerised 'made-to-measure' system was developed to allow the pattern to be drafted more effectively for non-standard sizes.

Since the made-to-measure system should have the capability of producing patterns for a well-fitted garment based on customer's body measurements, Turner and Bond[49] recommended the use of default formulae rather than mathematical interpolation of size charts when one or more of the customer's measurements were missing. Turner and Bond[49] then derived specific default formulae for the German DOB 'regular' and 'outsize' charts and also for the full range of 'height' categories and 'bust to hip' relationships, so that all sizes and shapes of customer are catered for. The German DOB system of charts was chosen because it is the most comprehensive national system and is also the basis for the European Standards. These derived default formulae, when applied to a given size chart set, enable measurements to be determined efficiently over wide-ranging customer sizes in terms of both stature and girth.

10.4 Three-dimensional (3D) apparel design systems for pattern generation and garment fit

Garment patterns have traditionally been produced from two-dimensional (2D) data consisting of lengths, widths and circumferences. Little information about the three-dimensional (3D) form of a body is contained in a typical data set. Pattern makers have supplemented data with qualitative descriptions of body variation for more accurate specifications of the body form, but such descriptions have obvious limitations in pattern production. The inadequacy of such data for drafting individual patterns has long been recognised.[50]

The CAD systems which have been developed have certain limitations in representing the complex 3D shape of the human body in terms of a 2D drawing. Studies on the computerisation of the garment design process have focused mainly on the generation of accurate flat patterns.[51,52] Research has therefore been carried out to develop more realistic 3D methods which could produce optimum patterns and achieve good fit.

10.4.1 Pattern generation from 3D data

Appel and Stein[53] produced a bodice pattern using a pair of photographs representing data of the human body from the front and side views; a blouse formed with various planes being manually superimposed onto the photographs. In order to make certain that the points on the plane are coplanar, either triangle or trapezoid planes were used as shown in Fig. 10.4. The vertices of the planes were digitised and Cartesian coordinates determined for each vertex. The three-dimensional design was displayed on a computer for visual verification. The planes were then projected and assembled to complete the pattern. The resultant pattern was well fitted to the subject with only one minor alteration necessary at the shoulder.

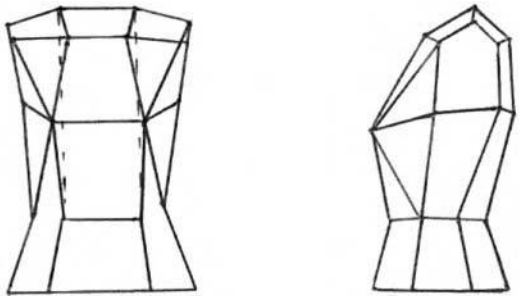


Figure 10.4 Design of blouse superimposed onto photographs of the human body. Source: Appel and Stein, 1978.[53]

Hutchinson and Munden[54] revealed that the workroom stands which are used as the standards for modelling garments in the industry were significantly different in their three-dimensional characteristics from those of the subjects measured. Hutchinson and Munden[30] therefore developed a method of assessing body shape, which consisted of moulding the body in polyethylene foam sheeting. The moulds were then cut at selected places so that they took the form of two-dimensional shapes. From these shapes an average shape was derived which was used to produce an average block pattern. It was found that the average block pattern provided a better fitting garment than the industrial block pattern.

Efrat,[55] however, found that Hutchinson and Munden's method, apart from the angle and forward slope of the shoulder, appeared not to be completely satisfactory for all body parts. The pattern shape was still the most important aspect to be evaluated. He then suggested a method to produce patterns of acceptable fit for the female bodice.

Efrat[55] developed the conical principle, which was intended to establish two-dimensional co-ordinates for the crucial pattern shaping points. The bodice was specified with 26 crucial shaping points, as shown in Fig. 10.5, which included the apex of the bust, the apex of the shoulder blade, and three or four points on either side of the pattern perimeters; the waist, side, neck, armscye (armhole) and shoulder. The bodice was then defined by 31 triangular planes; 16 for the front and 15 for the back panels. The bust and shoulder blades were the two prominent points, which were used to generate these triangular planes. A schematic diagram is shown in Fig. 10.6. Each triangle was formed by connecting two adjacent perimeter points and the appropriate apex. Orthogonal projections of the triangles were assembled to produce front and back bodice patterns; proportional corrections were made in the back shoulder area for the difference between the Euclidean distance calculated from coordinates and the actual curvature of the back.

Efrat[55] concluded that the problems associated with achieving good-fitting garments are caused by the unsatisfactory nature of the measurements obtained

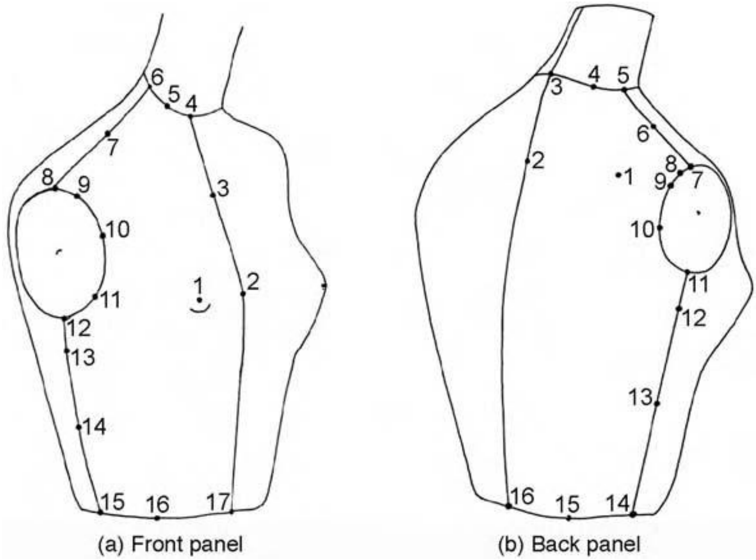


Figure 10.5 Location of the crucial shaping points. Source: Efrat, 1982.[55]

when measuring the human body by the traditional methods, and that the traditional methods of body shape determination are far from accurate. Therefore, a scientific investigation into the problems of achieving a two-dimensional block pattern which accurately reflects the three-dimensional nature of the human body, could well be of extreme significance to the clothing and tailoring trades.

Appel and Stein[53] and Efrat[55] examined the use of computers to draft the bodice patterns from 3D data with satisfactory results. Nevertheless, their work has not been extended or explored further.

Because fitting a fabric to the surface of a 3D object is a time-consuming art, Heisey and Haller[56] developed a computational method for fitting 3D surfaces with flat fabrics, using a mapping algorithm based on Mack and Taylor's[57] definition of fit; namely, 'the fabric is everywhere in contact with the surface.' They thought that a better understanding of the relationship of a 2D fabric fitted to a 3D object could aid in the automation of the customised production of garment patterns.

Heisey *et al.*[58] initiated a theoretical framework for drafting individually fitted patterns based upon modelling the physical process of draping a 3D garment. They noted that the 3D form of a garment does not exactly duplicate the surface of the body. Some parts of a garment may lie parallel to the surface of the body while others may be indirectly related to the underlying surface of the body. Figure 10.7 shows the mapping of a garment which lies parallel to the lateral surfaces of the bust and the back, and bridges the hollows between the breasts. Once the 3D form of a garment has been approximated then a projection

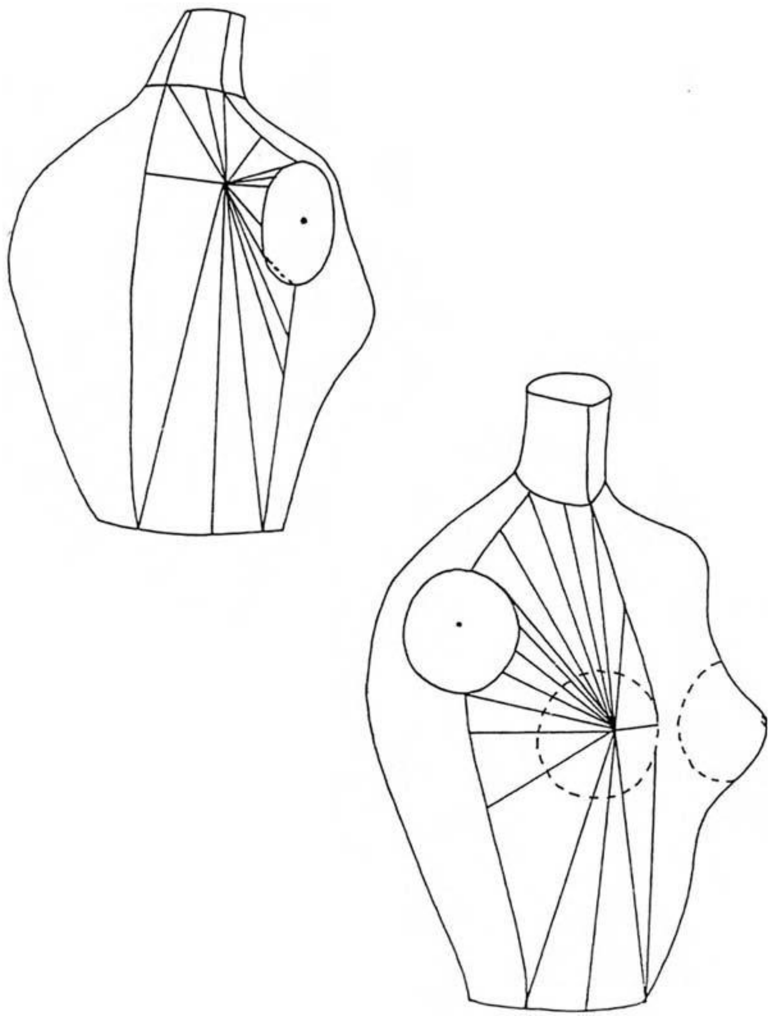


Figure 10.6 Division of the body into triangular sections. Source: Efrat, 1982.[55]

could be carried out to flatten it into a 2D pattern. They acknowledged that a sphere or any other dual curved surface is not applicable to a planar surface without distortion. It was difficult to define a projection which causes distortion to be acceptable or compatible with the end use. They also found that different fabrics might have different mappings and that very little work has been done on how fabrics conform to 3D surfaces. Their research may be regarded as the earliest published theoretical development of a 3D pattern design for garments.

Heisey *et al.*[50] found that the form of the garment which could be produced was typically restricted by arbitrary flattening procedures, which were not based on modelling the physical mechanisms of a fabric to conform to a 3D form and

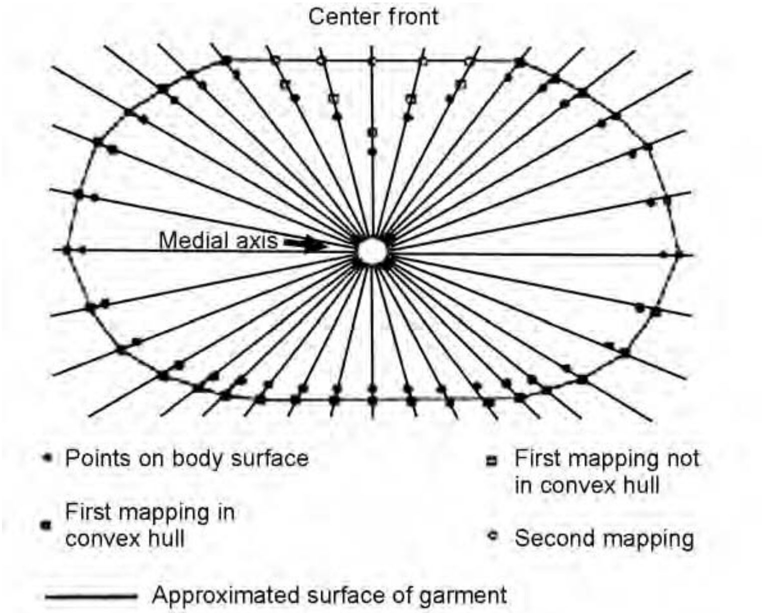


Figure 10.7 The mapping of the garment at the bust level. Source: Heisey *et al.* 1988.[58]

human judgement was needed to specify each individual garment. To overcome these restrictions, Heisey *et al.*[50] further developed an algorithm for computationally drafting patterns from 3D data based on their own theoretical framework.[58]

The procedure that Heisey *et al.*[50] developed to model the flattening of a woven fabric covering was basically a projection consisting of three steps: approximating the surface to be fitted with a mesh of polygons, projecting each individual polygon onto a plane, and combining the polygons to form a continuous pattern. They demonstrated the application of the algorithm in drafting coverings for a spherical object. A functional relationship for the fabric-flattening step of that framework for a woven fabric was developed. They found that the only factor which restricted the form to be fitted was the physical characteristics of the fabric.

Heisey *et al.*[59] further demonstrated their previously developed projection methods[50] in producing a 2D basic skirt pattern. In their research, they used the term 'last', which is used in the manufacture of shoes, to denote the form of an individually fitted garment. Such a 'last' rarely duplicates the area of the body to be fitted exactly, but rather specifies the space to be enclosed. They revealed that the functional relationship between the 'last' and the body is determined by a complex interaction of the garment, the form of the underlying body and the physical and mechanical characteristics of the fabric from which the garment is

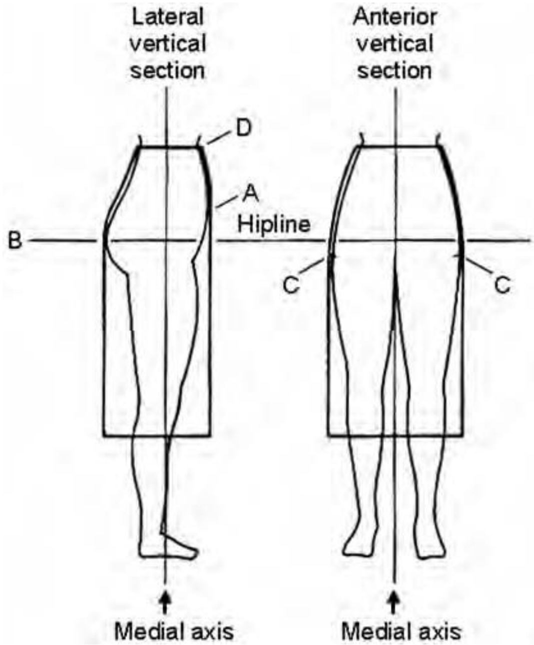


Figure 10.8 Diagram of two vertical cross sections of the body and a 'last' for a basic skirt. Source: Heisey *et al.*, 1988.[59]

sewn. A change in the form of the 'last' would change the style of the garment. The definition of a 'last' and style details for a basic skirt were used in mapping an individually fitted 'last' and projecting the 'last' to produce a pattern.

Heisey *et al.*[59] defined a 'last' for the basic skirt as a convex form from the waist to the point that was farthest from the medial axis (see Fig. 10.8). The 'last' followed the body's convex curves smoothly and bridged the concavities. The point on each vertical cross-section that was farthest from the medial axis was referred to as the rotational maximum for the section. Below the rotational maximum, the skirt hung parallel to the medial axis. Figure 10.9 shows a diagram of a basic skirt 'last'. The curve connecting points A, B and C connect the rotational maximum on each vertical section; this curve was referred to as the rotational ridge. Only the data corresponding to the specific region of the body was needed for mapping. The 'last' and style details for the skirt were mapped and the surface of the 'last' was projected using the developed algorithm.[50] It was demonstrated that the developed algorithm worked well.

Using a concept similar to that of Heisey and Haller,[56] Aono *et al.*[60] considered the fitting of a 2D cloth to a 3D surface so that it is everywhere in contact with the surface. They developed a mapping method to model surfaces, having double curvature, using flat patterns, assuming that the 2D cloth is deemed to have a limited deformational capacity, with inextensible vertical and

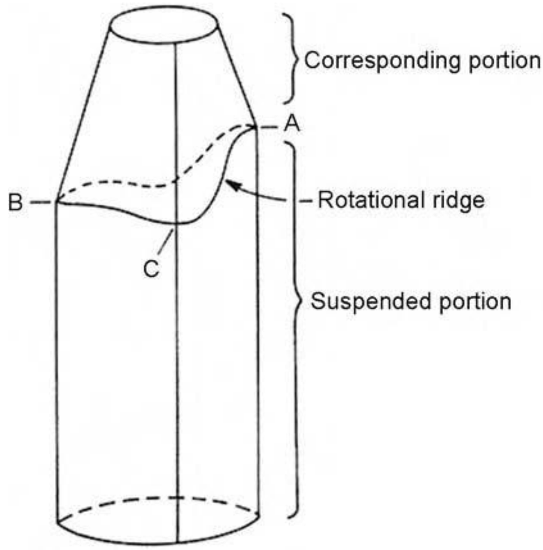


Figure 10.9 Diagram of a 'last' for a basic skirt. Source: Heisey *et al.*, 1988.[59]

horizontal threads, no curvature between thread crossings but with an ability to shear.

The above research was inevitably limited due to the difficulties in the acquisition of 3D measurement data. However, they provided a step to understand the relationship between the 2D shape of a pattern and the 3D form of the body.[61] With the advanced development of non-contact measurement methods, the use of quantitative data of the actual human body has become practical in many 3D CAD applications.[62]

10.4.2 3D apparel CAD developments

The main function of a 3D apparel CAD system is to provide a design environment for both garment and pattern development. The essential elements considered in the 3D software development are the access of a 3D human model by inputting the selected garment stand using a 3D digitiser or scanner for characterising the garment form; flattening from the 3D garment form to the 2D garment pattern; simulating the 2D pattern assembly and for a 3D visualisation of the garment design with fabric drape characteristics which help the designer earlier in the pre-production stage and for assessing the garment fit.

The computer generated 3D human model for accessing the garment form
Both manual and 3D CAD systems require a human model for pattern generation. The 3D human model can be generated by 3D contact or non-contact digitising techniques, both of which provide groups of set points to identify the

3D form. The 3D digital digitiser determines and records the co-ordinates of the intersections of the points on the stand at set latitudes and longitudes. A surface can then be created using this array of co-ordinates. Systems using 3D contact digital digitising techniques include those of Asahi AGMS-3D,[63] Okabe *et al.*,[64] Ito *et al.*,[65] Hinds and McCartney[66] and McCartney and Hinds.[67]

In developing the human model generator, Kang and Kim[68, 69] divided the human body model into several virtual cross-sections parallel to the floor, from the neck to the thigh, and the shape of each section was measured using a sliding gauge. Each cross-sectional shape was divided into 60 sectors and the radius obtained by image analysis, whereafter the body model is reconstructed in the cylindrical co-ordinate system using this data. The selected cross-sectional values, such as the neck, bust and hip from the anthropometric data, were used as the standard to develop a resizable human body model generator. Different growth ratios of the selected sections were considered from the statistical anthropometric data to obtain a realistic body model. Figure 10.10 shows the selection of base sections and an example of different growth ratios for the bust section. This resizable human body model is easily used in garment drape shape prediction as well as in the validation of the pattern grading process for mass production in commercial applications.

It has been concluded that although the 3D contact digital digitising technique provides an accurate model, the digitising process is very slow and for accuracy can only be performed on an inanimate object.[70]

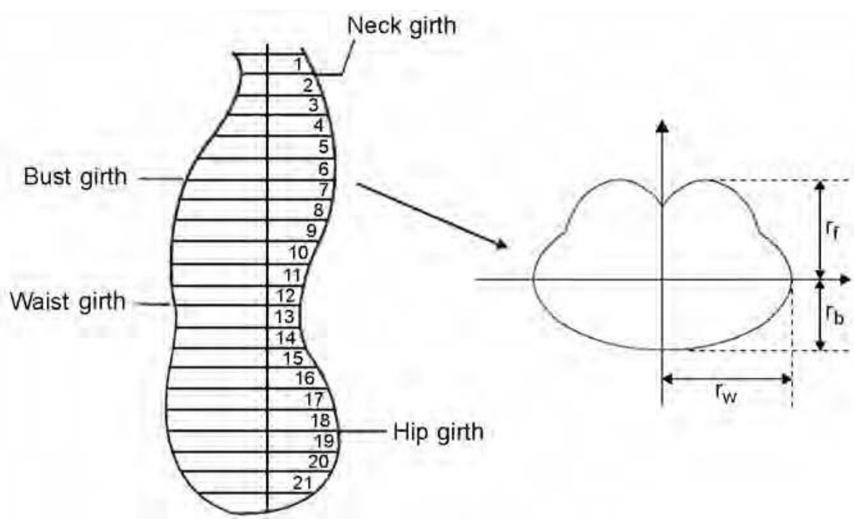


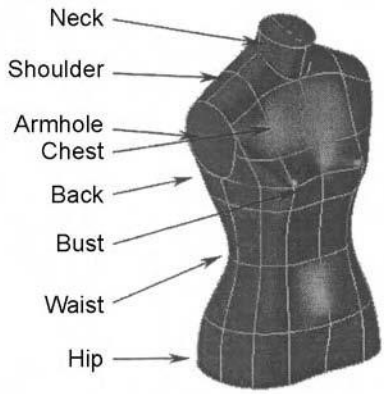
Figure 10.10 The selection of base sections and an example of a different growth ratio for the bust section. Source: Kang and Kim, 2000.[68]

With the development of the 3D non-contact digitising technique, the use of real body data has become practically feasible. There are several systems using 3D non-contact digisiting techniques for 3D human model generation. Fozzard and Rawling[71, 72] used the 3D human model from a computer interface. Hinds and co-workers[73, 74] used the Loughborough Anthropometric Shadow Scanner system (LASS),[75] to improve the accuracy of the image captured and to develop a 3D model in their 3D CAD garment design system.

As reviewed by Chen,[76] the CDI-3D system of 'CDI Technologies Inc.' first generated a 'Wireframe' garment stand using 3D contact or non-contact digitising techniques. The garment stand generated in this system can be resized using a 'resize' program, which offers a proportional modification rather than an individual requirement. The 'surface' program generates a concrete 3D garment form surface onto which style lines can be placed. The form type, posture, shape and proportion can be visualised and manipulated to meet individual demands from the solid form garment stand at this stage. The 'Curve' program by 'NURBS' (Non-Uniform Rational B-Spline – a mathematical method for constructing curve lines in a CAD environment), offers different types of curve lines to be drawn as style lines onto the surface of the garment form surface.

A feature-based human model, consisting of the major features of the torso for garment design, was created by Au and Yuen[77] in a 3D apparel CAD project initiated and led by Yuen in Hong Kong in 1996.[78] A feature recognition algorithm was used to recognise the features of a human torso represented by a cloud of points to create the feature-based human model. Figure 10.11 shows an example of the generic feature model of a mannequin with detailed features listed. The feature-based human model can also be defined parametrically. The alteration of the dimensions can be 'input' through a standard user interface. The feature recognition algorithm can be used in designing tailored garments for a specific person, while the parametric feature model can be used for mass production.

Kim and Kang[61] refined an automatic garment pattern design system using 3D body scan data. A WB4 whole body scanner, developed by Cyberware of USA, was used to obtain the 3D body data. A body model was generated from the scanned data using segmentation and the Fourier series expansion method. Finding that it was difficult to make garment patterns directly from the body model, a bodice (garment) model based on the surface geometry of a standard garment dummy used in the apparel industry was then generated by a stereovision technique. Two CCD cameras which simulate human vision were used to capture the four panels (two fronts and two backs) of the dummy marked with grids. The stereovision algorithm was used to calculate the spatial co-ordinates of the grid crossing points. A bodice model, as shown in Fig. 10.12, was reconstructed by assembling the four panels using specially designed stereovision software.



Features	Neighbouring features	Feature geometry Form	No. of Vertices	No. of Surfaces
Neck	Shoulder		6	2
Shoulder	Neck, Back, Chest, Armhole		9	4
Chest	Shoulder, Armhole, Bust		6	2
Armhole	Shoulder, Back, Chest, Bust		5	4
Bust	Armhole, Chest, Back, Waist		12	6
Back	Shoulder, Armhole, Chest, Waist		14	7
Waist	Bust, Back		21	12
Hip (F_g)	Waist		14	6

Figure 10.11 The generic feature model of a mannequin with detailed features listed. Source: Reprinted from *Computer-Aided Design*, 31, Au and Yuen, 'Feature-based reverse engineering of mannequin for garment design', 751–759, Copyright (1999), with permission of Elsevier.[77]

3D CAD systems for 3D garment form generation

According to Sato,[63] a commercial 3D CAD 'AGMS 3D' system, which was developed by the Asahi Chemical Industry Company in Japan, can convert 3D images into 2D patterns and 2D patterns into 3D images. It can make a pattern in a short time whilst obtaining the actual image. The system can display pattern and 3D images simultaneously and the design can be made with either 2D patterns or 3D figures. The prototype stage can be viewed in the form of 3D images.

Chen[76] reported that another commercially developed software, 'The CDI Design Concept 3D' (CDI-3D), which was developed by 'CDI Technologies Inc.' in the United States, and then taken over by Lectra in 1997, can obtain

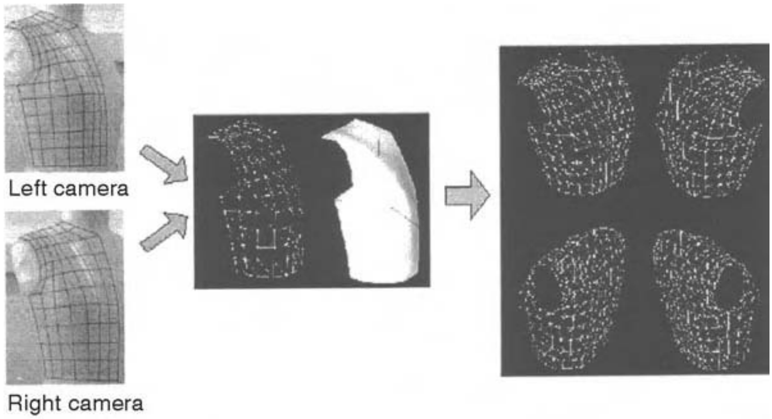


Figure 10.12 The generation of the bodice dummy; (a) a pair of images captured by two cameras; (b) reconstructed mesh structure and shaded surface for right front panel; (c) assembled bodice model with four panels. Source: Reprinted from *Computer-Aided Design*, 35, Kim and Kang, 'Garment Pattern Generation from Body Scan Data', 611–618, Copyright (2002), with permission of Elsevier.[61]

'contact-fit' patterns from 3D surfaces through five major programs, namely; the 'resize' program, the 'surfaces' program, the 'curves' program, the 'regions' program and finally the 'draping' program. The first three programs are used to develop the garment stand to generate the 3D garment forms. The latter two programs are used to flatten the 3D form into 2D patterns and for visualisation of the final result.

There are other commercial 3D CAD systems available, such as Gerber Technology, PAD, Investronica Inc., Optitex and Lectra. These systems incorporate the ability to apply a flat pattern to a 3D form or fit a model to see how a pattern will look when stitched together. Hence, fit problems can be identified and the flat pattern can be altered before an actual garment is cut and sewn. Nevertheless, published information is scarce.[79, 80]

In the CIMTEX (Computer Integrated Manufacture in Textiles) project, Fozzard and Rawling[71, 72] proposed developing a software system for garment CAD which could simulate pattern shapes from a conventional 2D CAD system in a 3D garment visualisation environment. The concept of the system allows marks to be made on the garment after dressing and draping in 3D. These marks can be examined on the corresponding panel in 2D and vice versa. The development can allow modifications made to a flat panel piece to be viewed in the completed garment without a physical prototype.

Okabe *et al.*,[64] developed what they regarded as 'the first 3D apparel CAD system', the core of which is a simulator which estimates the 3D form of a garment placed on a body from its paper pattern (2D to 3D process) as well as developing a program which minimises the energy required to deform the given

3D shape to obtain the 2D pattern (3D to 2D process). The system allows the designer to design in 2D or 3D, and to adapt shapes in the 3D environment to automatically generate the new patterns. As a consequence of the mechanical calculation in the system, the visualisation of distortion and stress in the garment panels can be used as a measure of the body contact pressure to assess garment fit.

Ito *et al.*[65] proposed an approach to develop an automatic pattern making system which could generate an appropriate garment pattern by inputting an initial designer sketch of a garment and to simulate the generated pattern to provide a 3D garment visualisation in the computer. Any alterations made to the original design sketch by the designer can be reprocessed into an improved pattern generation. The conceptual approach proposed was to develop an expert system which would transfer the designer's concept and a corresponding extensive garment description database for automatic pattern generation and visualisation of 3D garments. As concluded by Ito *et al.*,[65] the simulation was basically made by the interpolation of the actual measurements; a theoretical treatment method should be developed to realise the system for general use.

Hinds and McCartney[66] developed a method to provide a 3D tool for the designer to create a garment as a series of connecting panels around a 3D generated human form. A panel is defined as a generated surface which follows the contours of the underlying body form and bound by a series of edges. Points along the edges of each garment panel and the offset, which is defined as the length of the surface normal from the body to a point above the body surface, specified garment 'fit'. When the points along an edge are specified, the edge can be generated using curve-fitting algorithms. They concluded that the proposed method of garment design offers the way for storage of the 3D data and offers the opportunity for automatic pattern generation.

McCartney and Hinds[67] considered the garment pieces to be designed as a surface offset from a human form. Surface points on the dummy were mapped onto curvilinear coordinates to describe the body form. The B-spline method was used for 3D surface fitting. The Bezier form was used for user-defined geometry manipulation of the curves in 3D in the 3D CAD system which was developed. When garment design is considered, some degree of fullness may be added or an offset surface may be required for a particular region of the 3D surfaces due to a significant effect of the material thickness for garment piece generation. The curve-fitting process of the system can be extended to include editing of the offset behaviour. Then, an accurate panel periphery can be designed in 3D which incorporates variable offset values along individual edge curves of the panel. McCartney and Hinds[67] claimed that the developed 3D CAD system could rapidly specify complex garment pieces with variable fit.

Later, Hinds and McCartney[74] improved the computer hardware, which enabled realistic garment images to be created within acceptable time scales, for designers in the clothing industry. The software allowed the relatively complex shapes and textures of garments to be specified with the minimum input of data by the designer.

In order for a CAD system to be of practical use to garment designers and manufacturers, McCartney *et al.*[81] proposed two approaches in their development. With an accurate drape algorithm, the 2D patterns of a chosen fabric can be attached to the mannequin for 3D garment visualisation. The 2D patterns can be altered and re-run when changes are necessary. Another approach is to specify garment pieces in 3D with advanced drawing tools. Then the expert rules are used to process the 3D garment piece for the 2D shape with constructional details required to achieve the final form. To achieve this, McCartney *et al.*[81] proposed that the garment specifications should be divided into fit and drape areas. In the 3D CAD development, they outlined a framework for a possible computer integration approach which would accomplish the integration of the design interface, the pattern flattening and the fabric drape engine. The design interface enables 3D specifications of the garment to be created. The 3D specification provides an accurate surface description in areas where fit is important. The 3D surface representation of the garment provides a 3D framework within which panel relationships of garment composition can be defined. It also provides a reasonable starting point for drape simulation. The flattening process flattens the fitted areas differently from the draped areas, with the anisotropic nature of fabric characteristics being considered.

Kang and Kim[68, 82] developed a comprehensive apparel CAD system and integrated it into a 3D garment drape shape prediction system with a resizable human body model generator. The integrated 3D CAD system can perform automatic flat garment pattern drafting and can generate grading rules as well as engineering patterns, which can be used in the prediction of the final draped shape of a designed garment on the human body.

Later, Kang and Kim[69] developed a direct pattern generation method, using a body-garment shape matching process, to substitute the traditional trial and error garment fitting process in developing the 3D apparel CAD system for automatic garment pattern generation. A typical garment model was replicated by applying stereoscopy on a general-purpose dummy model, which is usually used in pattern making. Then, an algorithm was developed to adjust the shape of the garment model to fit the human body thus obtaining an individually optimum fit garment pattern. Finally, a pattern-flattening algorithm which flattened the adjusted garment model into 2D patterns was developed which also considered the anisotropic properties of the fabric to be used.

An algorithm has been developed to adjust parametrically a garment piece to fit a particular body while maintaining its styling. Any misfit of the garment can be fine-tuned by using the Free Form Deformation (FFD) algorithm to control the dimensions of the garment at different positions by altering and adjusting the control grid. The garment can also be adjusted interactively on screen, and the new pattern for the adjusted garment thus generated.[78]

Wang *et al.*[83] further used the feature-based approach for intuitively modelling a 3D garment around a 3D human model using 2D sketches as input. It aimed at providing a 3D design tool to create garment patterns directly in the 3D space through 2D strokes. The approach consists of three parts: a feature template is first constructed for creating a customised 3D garment according to the features on a human model; the profiles of the 3D garment are specified through 2D sketches; and finally, a smooth mesh surface, interpolating the specified profiles, is constructed.

Wang *et al.*[83] introduced a prototype model to show the various modification operations of the system. Strokes could be input by the user to specify the silhouette of the extruded surface. Strokes marked across the contour of the model in the cutting operation mode represented the cutting off of some part of the model. Seam lines could be painted in using drawing strokes within the model silhouette. The whole model could be separated into component parts according to the painted seam line and finally flattened into 2D patterns. Figure 10.13 shows the overview of the system operations.

Wang *et al.*[83] concluded that this system could regenerate patterns automatically when creating the same style of garment for other human models, as the garment patterns are constructed in relation to the features of the human

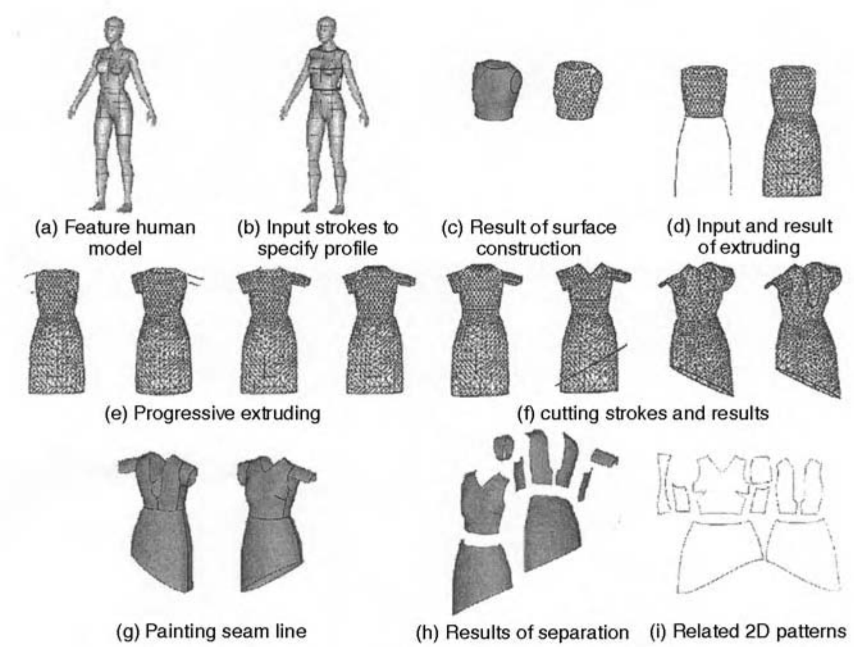


Figure 10.13 The overview of the 3D garment design system operations. Source: Wang *et al.*, 2002.[83]

model. Also, easing space is provided between the specified profiles and the cross-section of a human model; tightly fitting garments as well as loosely fitting garments can be constructed using this approach.

The flattening of the 3D garment form into a 2D garment pattern

Automatic pattern generation is seen as a major aim of 3D CAD system development, requiring a method to generate the 2D pattern shapes from the 3D prototype. Noting that the process to flatten a curved surface into a plane is different from the process to force a pattern from a plane surface into the curved shape of a garment, Okabe *et al.*[64] proposed using cylindrical mapping to derive the panel shape, which can be refined after meshing and re-simulating the position of the panel into 3D space.

Hinds *et al.*[84] demonstrated an approach to derive garment pattern pieces from the designed 3D models at a CAD station. An offset surface with respect to the underlying body form which represents a piece of a garment was created. A grid of points was necessary for pattern development for this surface. Primary and secondary spines were first defined. Using these spines and starting out from the origin, a grid on the 3D surface could be formed. A Newton-Raphson algorithm was used to iterate the intersection of an approximately equal-sided mesh to the complete surface of the garment as shown in Fig. 10.14. The mesh grid was trimmed later for the garment pattern as shown in Fig. 10.15. The small darts on the pattern were grouped together to form a single dart at a specific location. An alternative to the Newton-Raphson algorithm was a radial-mesh development as shown in Fig. 10.16. Hinds *et al.*[84] concluded that the developed methods were based on the simple concept of modelling a doubly curved surface as an assembly of triangular platelets. Groups of such platelets can be flattened onto the plane to obtain the overall pattern, which reflects the type of curvature on the original 3D surface.

Hinds *et al.*[73] developed a software aimed at improving the '3D to 2D' flattening and simulating '2D to 3D' drape. This development enables the cursor to move around the surface of the body form on the screen in the design system. The editing features developed for the system become a means of defining the 3D shape of the garment pieces with respect to the underlying body form. The 3D shape is then flattened depending on the degree of double curvature and type of curvature.

McCartney and co-workers[81,85] developed an algorithm for flattening 3D surfaces described in terms of a list of triangles. By selecting groups of these platelets as strands of the pattern, each group could be flattened onto a two-dimensional plane. The resulting pattern contained darts and gussets, which could be approximated to provide a more realistic pattern shape in the fitting process for garment design purposes.

A flattening algorithm developed by McCartney *et al.*[85] was used for 2D flattening in the 3D CAD system developed by McCartney *et al.*[81] The

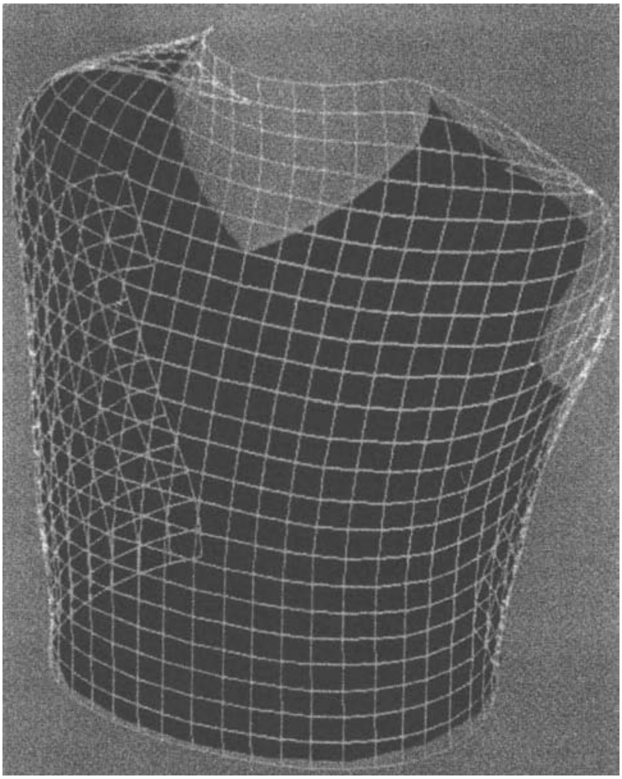


Figure 10.14 Garment piece with a superimposed equimesh grid. Source: Reprinted from Computer-Aided Design, 23, Hinds *et al.*, 'Pattern development for 3D surfaces', 583–592, Copyright (1991), with permission from Elsevier.[84]

algorithm was capable of handling the arbitrary siting of seams, darts or gussets depending on the nature of the curvature involved. The 2D flattening specifications involved a full interior description of how the garment was mapped from 3D to 2D, which would enable the reverse process to be achieved when the draping was considered. Examples of the integration of the design interface, the pattern flattening and the fabric drape engine are shown in Fig. 10.17.

Kim and Kang[61] developed the surface-wrapping algorithm to make an equalised geometry of a body model and the garment model, and a multi-resolution mesh generating algorithm together with an optimum planar pattern mapping algorithm were used to generate the optimum 2D patterns for individual body shape. They revealed that these automatically generated patterns were somewhat different in overall line shape or dart location compared with the manually designed patterns, which may be due to the limitations of conventional methods to reflect accurately the 3D features of the human body in flat patterns.

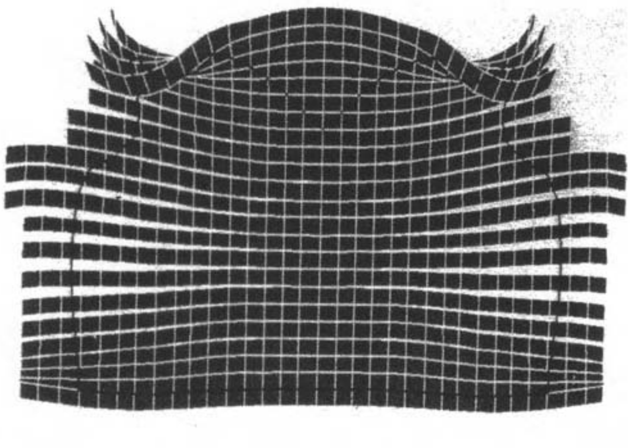


Figure 10.15 Multistrand garment-piece pattern. Source: Reprinted from Computer-Aided Design, 23, Hinds *et al*, 'Pattern development for 3D surfaces', 583--592, Copyright (1991), with permission from Elsevier.[84]

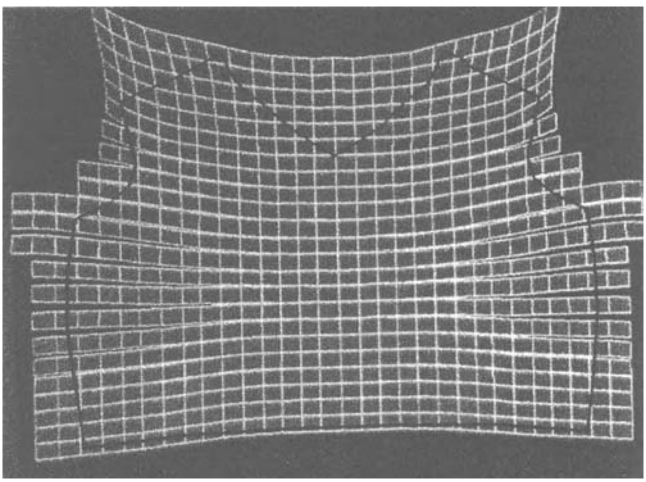


Figure 10.16 The Overlaps eliminated by the spreading out of strands. Source: Reprinted from *Computer-Aided Design*, 23, Hinds *et al.*, 'Pattern development for 3D surfaces', 583–592, Copyright (1991), with permission from Elsevier.[84]

Wang *et al.*[86] demonstrated a method for 3D surface flattening to be used in the 3D CAD system developed by them.[83] A facet model was used to present a complex model. Then a spring-mass model based on energy functions was used to flatten the resulting mesh surfaces into 2D patterns. They believed that the method can efficiently solve the flattening problems for complex surfaces.

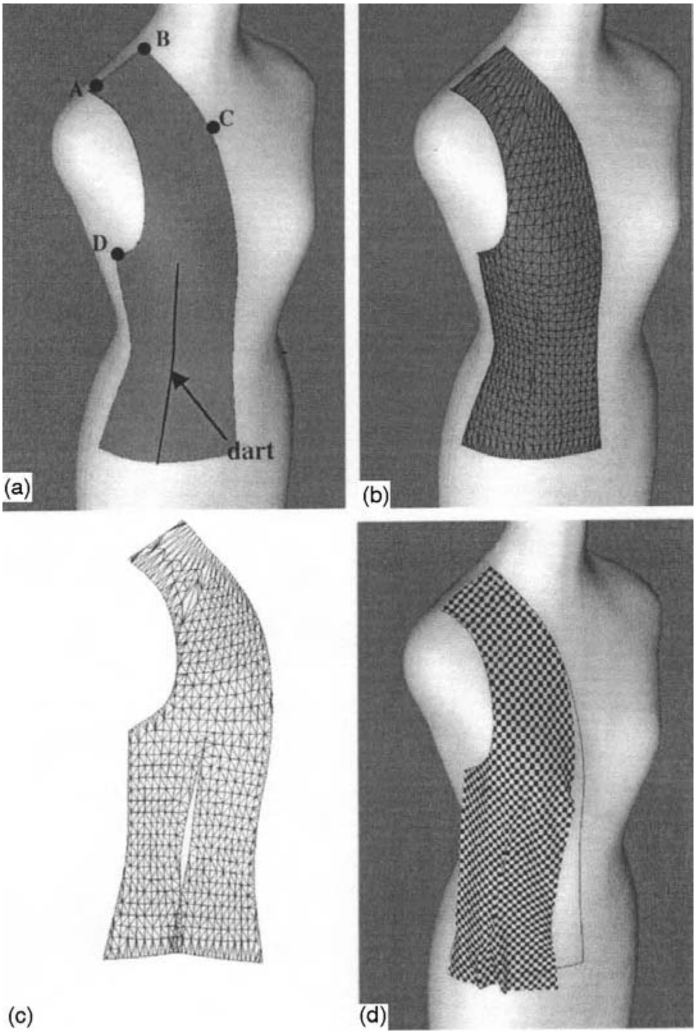


Figure 10.17 The integration of the design interface, the pattern flattening and the fabric drape engine, a) stylished 3D garment panel design with dart, b) garment panel triangulation with dart, c) 2D flattening of panel with dart, d) 3D drape of panel with texture rendering. Source: Reprinted from *Journal of Materials Processing Technology*, 107, McCartney *et al.*, 'Dedicated 3D CAD for garment modelling', 31–36, Copyright (2000), with permission from Elsevier.[81]

The fabric model and garment fit

Fabric selection is an important part of garment design. The fabric model is required to predict the shape of the draped fabric in real time with links to mechanical data to enable different fabric types to be modelled. Fozzard and

Rawling[71, 72] identified a drape algorithm for incorporation into a dressing visualisation system into their CIMTEX project. To simulate fabric drape in the system, the finite element modelling technique combined with NURBS surfaces were used. A fabric objective measurement database was developed within CIMTEX for interfacing with the system.

In the work proposed by Okabe *et al.*,[64] the specific anisotropy of the mechanical properties of fabrics is considered in both the 3D to 2D and 2D to 3D processes. In the 2D to 3D process, the contact problems with body and geometrical nonlinearity are also taken into account. As a consequence of the mechanical calculation, the distributions of the distortion and stress in garment panels are also visualised, which can be used as a measure of body contact pressure to assess garment fit.

Hinds *et al.*[73] revealed that adjustments are required for plane 2D materials to fit a 3D surface. They concluded that material might be added to create drape in some cases and might be absorbed in other cases. In their work, they found that the distortion or stretch of the fabric helped the fitting process.

To visualise the actual draped shape of the garment on a human model, the finite element analysis method was developed as well as computer graphics to obtain and demonstrate the 3D drape shape. The flat pattern pieces were divided into fine quadrilateral elements using a specially coded mesh-generating program and appropriate sewing conditions are assigned to transform 2D patterns into 3D shapes. The strain reduction and pseudo-drape methods are used in the garment drape shape prediction system. Kang and Kim[68] concluded that the final drape shape prediction was determined from the solutions of the contact condition with the human body; deformations, and the weights of the elements constituting the garment pieces, as well as the surface texture of the fabric. They also revealed that the precise variables for material behaviour are tensile strain energy constants, in the warp and the weft direction; shear strain energy constant; out-of-plane bending energy constant; and potential energy resulting from fabric mass. The model, which embodied these energy and geometric modelling elements, was termed a drape engine.

In the 3D software developed by Yuen,[78] the pattern from a 2D CAD system was inputted into the computer using the standard DXF format. Sewing, fabric and positional information were also inputted to allow the construction of the garment by assembling the patterns around the feature-based human model.[77] The assembled garment could be shown in its constructed or draped format, with a choice of fabric properties and texture. Fast collision detection and self-collision detection algorithms were used to facilitate the draping process and show the draping effect of different fabric garment properties and textures. In the system, the facility of viewing the assembled garment in translucency and the fabric stressing display mode provided a useful tool to evaluate the fitting of pattern and garment and the choice of fabric.

10.5 Virtual fitting on the Internet

Today's consumers have less time to shop around for proper fitting garments. They are more likely to carry on buying at retailers who consistently offer products which fit them. Some consumers may enjoy the convenience of catalogue or Internet shopping, but many may not purchase apparel this way because they are sceptical as to whether the garment will fit once it is delivered. Apparel fit problems are costly and frustrating, not only for consumers but also for apparel manufacturers and retailers, the costs resulting from returned merchandise, lost sales, brand dissatisfaction or time wasted in the fitting room.[79, 87, 88] Moreover, nowadays the apparel industry has changed from mass production to customised and versatile production in order to satisfy the consumer's desire for more individuality, thus the waste of resources and time and the traditional fitting trials become a major problem.

It has been found that the major source of fit problems are:

- lack of standardisation
- problems with size standards and grading rules
- shortcomings in pattern making
- manufacture-driven conflicts
- consumer and industry perceptions of the body.

With the super-rapid pace of technology advances and the promise of new sizing data on the horizon, solutions are beginning to abound.[87, 89]

10.5.1 The Web-enabled body scanner

To overcome the problems of lack of size standardisation and inappropriate grading rules, and the different perceptions of body shape from consumers and industry, apart from industrial surveys and studies to update consumer size, shape and fit preference data, automated body scanners have become one of the most powerful tools for obtaining 3D shape data to improve garment fit. Several advanced body scanners have been developed to be Web-enabled. The scanned data thus obtained can be transmitted via the Internet to a central database or to manufacturing locations from remote scanner locations.

The 'ImageTwin' (TM) system, which was formed by the joint venture between the Textile Clothing Technology Corporation (TC^2) and Konover Property Trust, was the first to deploy body scanners in commercial retail settings. The 3D body scanners were installed at various retail mall locations to obtain measurement data from consumers. The scanned data was then entered into a confidential database, which can be accessed by partner retailers for order fulfilment and by other retailers and manufacturers on an anonymous, data-for-fee basis. The consumer can access his or her scanned data for order placement via the Internet, or via a store or catalogue for clothing items.[87, 90]

The Tecmath AG's 3D body scanner from Germany, integrated with measurement software, can collect and automatically download scanned data into programs, such as made-to-measure systems.[91] There are other Web-enabled 3D body scanning technologies, such as the system from Clarity Fit Technologies, which can take scanned data and convert it into custom 2D patterns.[92] The Battelle Pacific Northwest National Laboratory (PNNL) has invented a high-speed body scanner 'Battelle' which can obtain human body measurements through clothing, thereby eliminating the need for a changing room.[93]

10.5.2 Services from Web-enabled scanning

ImageTwin's proprietary 'Best Fit' size prediction software can help the consumer to identify the best fitting garments for sale from partner retailers and brands from the scanned data. The Tecmath enables retailers to offer customised clothing options to consumers. Clarity Fit Technologies offers services for helping firms to improve their size standards and patterns. The Clarity Fitting Room of the firm assists consumers in online apparel shopping. Clarity Fit's solution can provide size recommendations based on consumer measurement data, fit preference data and the manufacturer's or retailer's garment specification data. The Clarity Fitting Room's proprietary visualisation technology displays how garments could fit an individual consumer in various sizes, such as loose, tight, recommended, etc. The 3D Custom Fit Corporation has developed a process utilising the 3D relational-geometry principle to automatically mould 3D basic blocks to fit over individual body scans. These 3D blocks are then flattened into 2D garment patterns which can be incorporated into standard CAD packages to create perfectly fitting garments without the use of measurements.[87]

IC3–D (Interactive Custom Clothes) is beginning to produce custom-made jeans based on information from body scanners. Brooks Brothers embraces the use of theTC^2 body scanner in its flagship store to act as a 'digital tailor' for its customised clothing business. This technology enables detailed measurements of their customers to be captured at the time of sale, thus ensuring a better fit, higher production efficiency and ultimately higher customer satisfaction.[88]

10.5.3 The virtual fit engines

Most consumers remain reluctant to buy garments online because they cannot try them on to ensure proper fit. Internet retailers have begun to implement virtual fit technologies on their websites to attract more shoppers to these sites, improve fit prediction, and decrease the number of returns. The virtual fit technology enables consumers to develop a 'virtual model' which 'looks' like them by entering a series of measurements and shape parameters, and then choosing from a variety of facial, hair, and skin types to design a 'virtual model'. The consumer can click on garment images at a retailer's site while visiting participating retailers online and see how the clothing looks on the virtual model.

There are many virtual fit developments online offering 3D cyber mannequins for virtual trying-on, such as Browzwear's C-me, Clarity Fitting Room of Clarity Fit, DigiTex and DigiGarments of DigiBits Interactive, WebFitting of DigiBits Interactive, Vtryon of Enfashion, My Virtual Model and Virtual Dressing Room (VDR) of yourfit.com. In addition, Imaginarix's Click&Dress uses the consumer's own photographic images and Virtual 3D uses 3D images for visual effects. The Digital Fitting Room of MySize Systems can tie in with other 3D cyber mannequin solutions. Though EZsize and TheRightSize do not use a 3D cyber mannequin for visual effects, the EZsize provides a five-star fit rating and comments based on consumer's measurements while TheRightSize performs data analysis to recommend products based on what the consumer wears.[94]

Browzwear's C-Me combined with its flagship product, V-stitcher, can provide a 3D simulation of a 2D flat pattern. Manufacturers can see fit problems in virtual space before the sample is cut and made up. Problems can be identified and then corrected on the 2D pattern, thus saving time and development costs.[88]

'My Virtual Model', which is based in Montreal, and 'PlusSize.com' websites offer virtual trying-on or virtual fitting rooms. Consumers just need to enter a limited set of variables, such as weight and height and then choose a type of body shape from a few picture references to develop their virtual model virtually for trying on an outfit, and to mix-and-match styles. My Virtual Model provides personal shopping guidance by making clothing recommendations based on the individual's information and previously chosen styles. My Virtual Model's database on the size and fit of consumers is collected and aggregated and may eventually feed back to their retail partners so that they can gain a better understanding of the size, shape and consumer preferences in their target market.[87, 88]

Firms, such as EnFashion, EZsize, TheRightSize and YourFit.com, are targeting the size prediction marketplace. EZsize works with Saks Inc., Ann Taylor and Esprit de Corp. to integrate their merchandise offerings into the EZsize database. Consumers who input their measurements online via the EZsize service will be digitally matched with different garment choices.[87, 89] Furthermore, EnFashion considers not only consumer measurements but also the apparel manufacturer's DFX image of the paper pattern, fabric weight and elasticity and garment strength characteristics. The light and shadow renderings from computer simulation can illustrate the hang and drape of the fabric. The 'see-through' mechanism enables the consumers to see how well the garment fits in any dimension.[87]

Companies, such as Virtual 3D, are offering infrastructural tools which enable online retailers to display 3D images of products on their websites. The tools allow e-consumers to see, touch and feel a product through rotating, zooming and interacting with the images.[79]

10.5.4 Customisation from the Internet

Lectra has developed a solution called 'FitNet' which aims at addressing the needs for mass customisation. FitNet enables pattern makers not only to view their pattern constructed on a 3D model, but also to make adjustments to the garment in 3D and see those changes translated automatically onto the 2D pattern. It includes a server which allows each company to create its own collections, either online or through a sharing network. Consumers can design their own garments by selecting the viewed style, fabric, colour, trim, etc., available at point-of-sale, and then inputting their measurements through either measurement scales (chest, waist, hip, etc.), alterations to existing styles, or through body scanned data. The information can be sent electronically to a Modaris pattern-making system, where a customised pattern is produced and picked up by the Diamino marker making system, and a marker is automatically cut by the TopSpin cutting system. All these systems are linked through FitNet, garment fit can be ensured while production and delivery times can be reduced to a minimum.[88]

In addition to FitNet, there are a number of other solutions on the market which offer quick alterations to existing patterns to fit customisation and production automation. These include offerings from Optitex, Gerber Technology and PAD Systems.[80, 88]

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